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FIELD REFERENCE DOCUMENT

LEVEL II

AIRFIELD DAMAGE RECOVERY TECHNIQUES OF 18th ENGINEER BRIGADE IN EUROPE

by

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Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

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FOREWORD

This report is intended to present lessons learned from Europe on Airfield Damage Recovery (ADR) techniques. It was prepared by the 18th Engineer Brigade's 293rd Engineer Battalion, which has the mission of ADR. Basic concepts and techniques were researched at the U. S. Army Engineer Waterways Experiment Station (WES), CE, then recommended to the 18th Engineer Brigade and field evaluated by the 293rd Engineer Battalion under chemical-biological, reduced visibility, and wet-weather conditions. The collaboration between researcher and troop user has allowed immediate technology transfer and feedback.

The funding was provided by the Office, Chief of Engineers, U. S. Army, in direct response to questions asked by the Headquarters of the U. S. Army in Europe. This report was written by LTC T. Stroup and CPT D. Reed of the 293rd Engineer Battalion with special sections written by Dr. G. M. Hammitt, WES.

Commander and Director of WES during the preparation of this report was COL Nelson P. Conover, CE; Technical Director was Mr. Fred R. Brown. Commander of the 18th Engineer Brigade was COL James W. Vanlobensels.

TABLE OF CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per minute	0.02831685	cubic metres per minute
feet	0.3048	metres
gallons per square yard	4.5273	cubic decimetres per square metre
inches	25.4	millimetres
mil	0.0254	millimetres
pounds (force) per square inch	47.88026	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (2000 lb, mass)	907.1847	kilograms
yards	0.9144	metres

AIRFIELD DAMAGE REPAIR TECHNIQUES OF 18TH ENGINEER BRIGADE IN EUROPE

PART I: INTRODUCTION

Purpose

1. The purpose of this interim document is to provide documentation of airfield damage recovery (ADR) techniques within the 18th Engineer Brigade in Europe. This information can be used by the researcher and troop user alike to provide the repair of craters necessary to restore an airfield's horizontal construction to operational capability. The long-range purpose is to develop improved systems allowing a field commander to respond to various levels of hostility with a minimum of manpower, time, and cost. Current information within the state of the art of ADR can be used by units in the field for planning, estimating needed materials, organizing, and then accomplishing war damage repair missions to airfield pavements. The methods, materials, and techniques presented are those currently available for war-damaged airfield runways, taxiways, aprons, and roadways.

2. During the early periods of hostilities, the repair and restoration of airfield paved surfaces (REREPS) damaged by war are among the most significant engineer support missions. Lessons learned in Vietnam and the Israeli-Arab nation conflicts have illustrated the criticality of rapid ADR of specific air base facilities. The construction effort required will necessitate combined efforts of U. S. forces and participation of host nations. The Army engineer forces have the following responsibilities: (a) providing repair/restoration of war damage to air bases beyond that of emergency repair, (b) assisting the Air Force in the emergency repair of war damage to air bases when that requirement exceeds the Air Force organic capability, (c) base development excluding the Air Force bed-down responsibilities, and (d) construction management of repair/restoration of war damage and base development. In addition to paved surfaces, the Army is also responsible for

the acquisition, repair, improvement, expansion, and rehabilitation/construction of installations and facilities to support existing and deploying Air Force units. This support consists of rehabilitation/construction of such facilities as supply depots; petroleum, oil, and lubricants (POL) systems; and buildings and roads conforming to theater of operations (TO) standards of construction.

Background

3. On 29 August 1940 in London, Prime Minister Churchill wrote to the Secretary of State for Air.

> All craters should be filled in within 24 hours at most, and every case where a crater is unfilled for a longer period should be reported to higher authorities. In order to secure this better service it will be necessary to form some crater-filling companies. These should be equipped with all helpful appliances and be highly mobile, so that in a few hours they can be at work on any site which has been cratered. Meanwhile, at every aerodrome there must be accumulated stocks of gravel, rubble and other appropriate materials.

4. The ADR is the primary wartime mission of the 18th Engineer Brigade in Europe. Conceptually, little has changed since Winston Churchill's words on airfield repair were written. The current NATO standard is to recover an airfield for emergency operations within 4 hr of an attack. Developing realistic methods and training to meet the standard are no small tasks in light of the airfield damage to be expected after an attack with modern weapons.

5. Training management of ADR is a true challenge. No Army doctrine for prescribed procedures is available for airfield recovery, and one of the most important goals of the training program in the 18th Brigade is to develop Army Training and Evaluation Program (ARTEP) task descriptions, standards, and goals. Draft ARTEP Training and Evaluation Outlines (TEO's) have been developed for each different technique for use in the Brigade's training program. Recently, combat realism has been incorporated into the runway repair exercises with some exercises

conducted in full mission oriented protection posture (MOPP) gear, including protective masks. The operation of heavy equipment in a confined area under such conditions is a real command and control problem. Material procurement through host nation sources is expensive with unique staff coordination impacts. These areas represent only a few of the training management problems associated with a runway repair and ADR training program.

6. Within the 18th Engineer Brigade, the 293rd Engineer Battalion in Baumholder, Germany, has been charged with the mission of developing rapid runway repair techniques of a semipermanent/permanent nature (Figure 1). The battalion has done this in conjunction with the U. S. Army Engineer Waterways Experiment Station (WES), CE, in Vicksburg, Mississippi. Working closely with the scientists and engineers of the WES since 1976, the 293rd Engineer Battalion has participated in field/ operational testing of crater repair techniques (Figures 2 and 3). This testing by troops is being done on the training airfield at the Baumholder Training Area. This ongoing training has produced draft ARTEP TEO's; a field reference document, Airfield Damage Repair--published by the WES; draft technical reports on repair exercises; and doctrinal input from the 18th Brigade to the U. S. Army Engineer School, Fort Belvoir, Virginia. Training on other aspects of ADR, such as repair of utilities and restoration of facilities, is accomplished by all 18th Engineer Brigade units through its troop construction in Europe. The other combat battalions in the 18th Brigade--the 79th in Karlsruhe, the 94th in Darmstadt, the 249th in Karlsruhe--and the Brigade's 6970th Civilian Labor Group also train in crater repair using the techniques developed.

7. Current evaluation efforts have examined the two major components of crater repair: crater bowl preparation and placement of a crater cap wearing surface. Techniques examined or currently being evaluated are (Figure 4):

a. Regulated-set concrete.

b. BN 55, 25, 15 concretes.

c. AM2 airfield matting.

d. XM-19 airfield matting.

e. Full depth crushed stone aggregate.

f. Aggregate repair cap.

g. Aggregate/cement repair cap.

h. Asphalt.

i. Water-cement aggregate grout.

j. Reinforced earth.

k. Silikal[R].

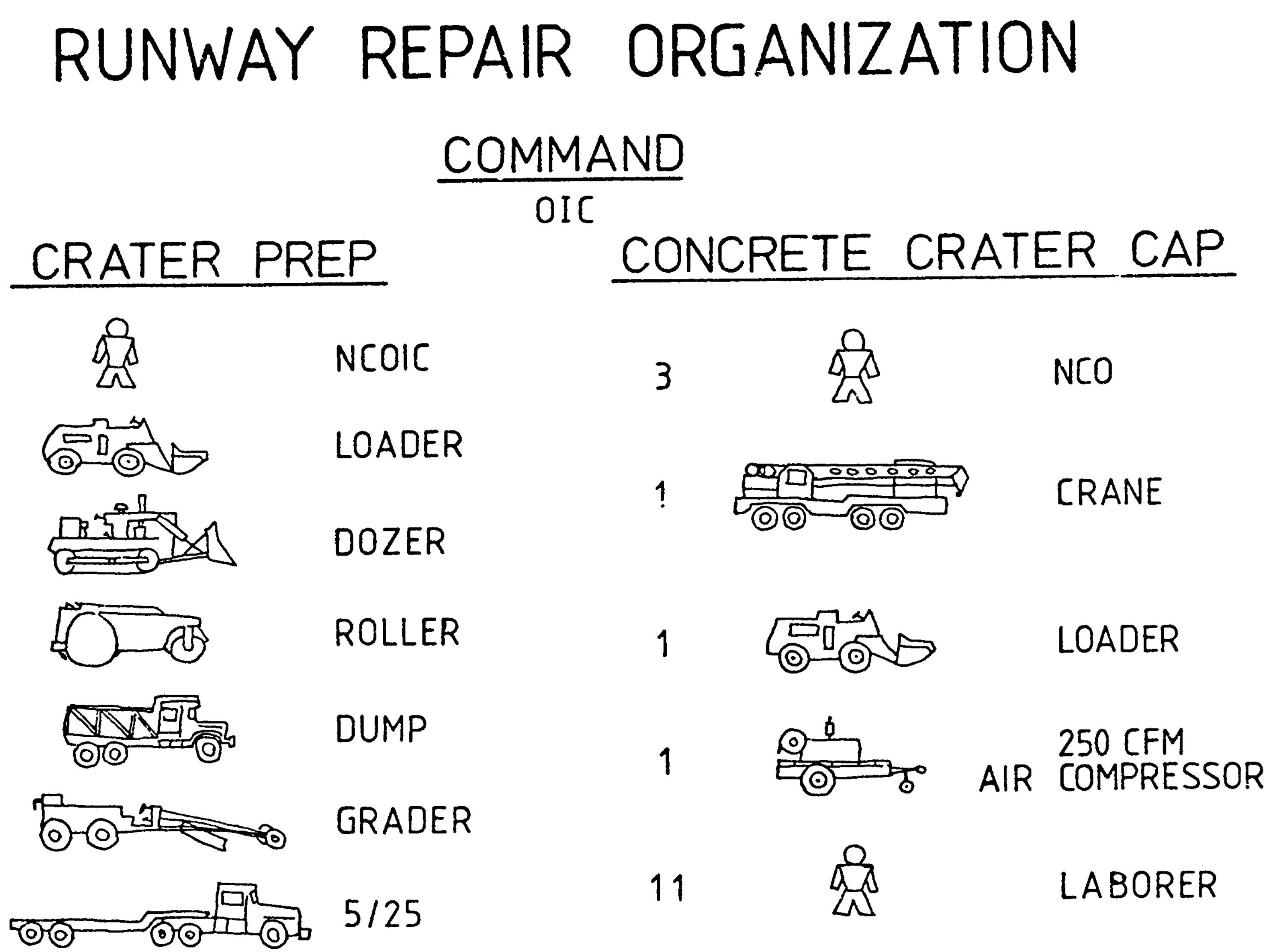
Sources of available aggregates for these techniques are given on a location map at the end of this report. Although these current techniques certainly do not represent the final solution for the crater repair problem, they do represent viable techniques within the 18th Engineer Brigade. The 18th Engineer Brigade will continue to set the pace for the Army in planning/developing ADR techniques for all phases of base recovery, to include the important area of crater repair.

AIRFIELD DAMAGE REPAIR MISSION

- RAPID DAMAGE ASSESSMENT
- EOD
- RESTORE TO EMERGENCY OPERATIONAL STANDARD
  - COMMAND & CONTROL FACILITIES
  - UTILITIES
  - ACCESS ROADS
  - POL SYSTEMS
- RUNWAY REPAIR (Craters, Spalls, UXO)

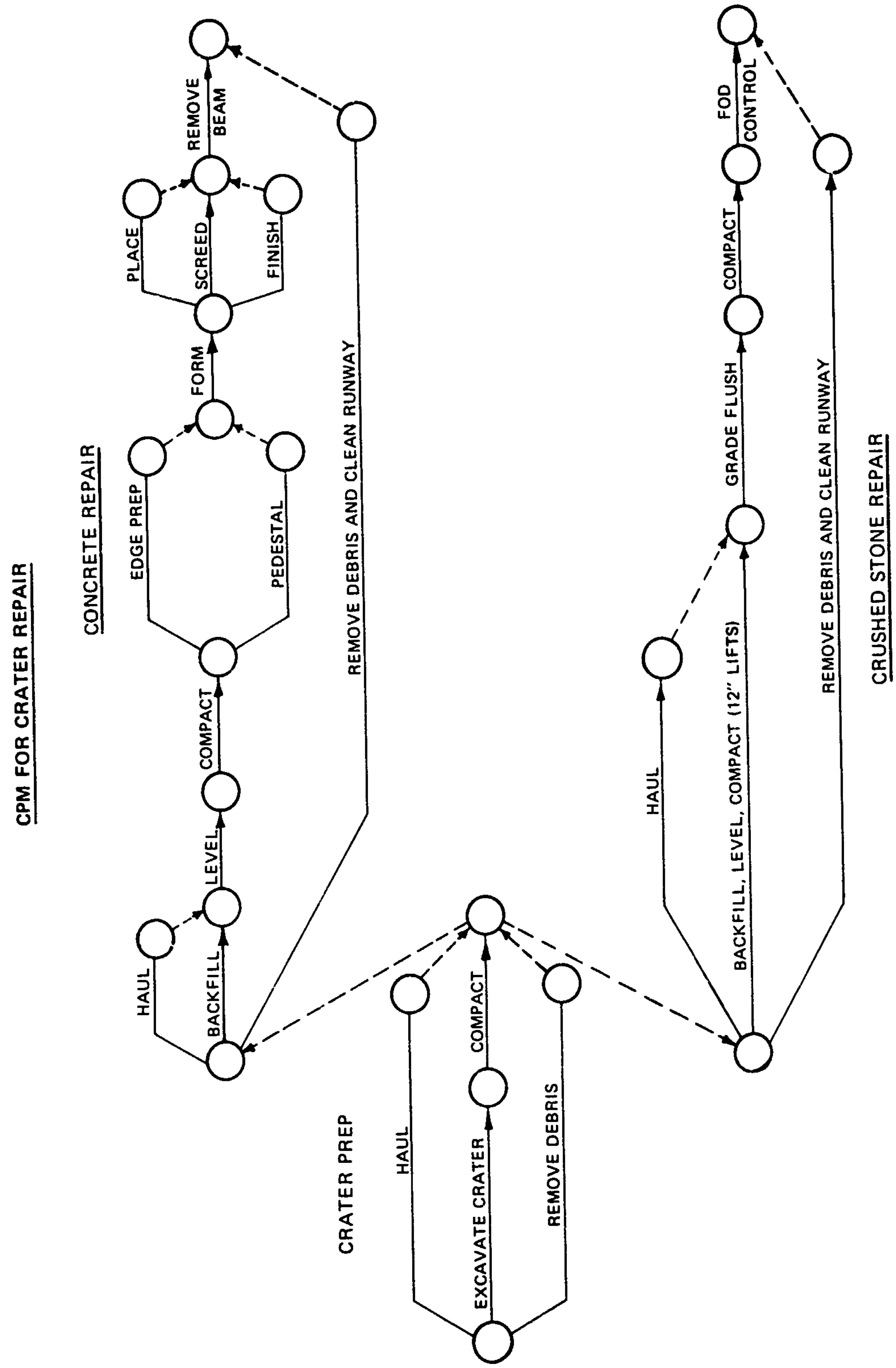
NATO STANDARD: 4 HOURS
TAC - 50' × 5000'
RECEPTION 75' × 7500'
12 - 14 LARGE CRATERS

Figure 1



RUNWAY REPAIR ORGANIZATION
COMMAND
OIC
CRATER PREP
1 NCOIC
3 LOADER
1 DOZER
1 ROLLER
5 DUMP
1 GRADER
2 5/25
CONCRETE CRATER CAP
3 NCO
1 CRANE
1 LOADER
1 250 CFM AIR COMPRESSOR
11 LABORER

Figure 2



CPM FOR CRATER REPAIR
CONCRETE REPAIR
HAUL
BACKFILL
LEVEL
COMPACT
EDGE PREP
PEDESTAL
FORM
PLACE
SCREED
FINISH
REMOVE BEAM
REMOVE DEBRIS AND CLEAN RUNWAY
CRATER PREP
HAUL
EXCAVATE CRATER
COMPACT
REMOVE DEBRIS
CRUSHED STONE REPAIR
HAUL
BACKFILL, LEVEL, COMPACT (12" LIFTS)
GRADE FLUSH
COMPACT
FOD CONTROL
REMOVE DEBRIS AND CLEAN RUNWAY

Figure 3

REPAIR TECHNIQUES

TECHNIQUE	TIME (HRS) WORK COMPLETE	TIME (HRS) RUNWAY OPERATIONAL	TRAINING COST/CRATER
AM-2 MATTING	3	3	$ 16500 (REUSABLE)
XM-19 MATTING	3	3	$ 24300 (REUSABLE)
UNSURFACED GRAVEL	3	3	$ 3600
GRAVEL W/CEMENT	4	4	$ 4500
ASPHALT	4	28	$ 16000
BN 250 CONCRETE	3	160	$ 5600
BN 550 CONCRETE	3	8	$ 11000
REG SET CONCRETE	3	4	$ 12100

Figure 4

PART II: CRATER REPAIR TECHNIQUES

Full Depth Crushed Stone Aggregate

Purpose

8. The purpose of this field test of project REREPS was to evaluate the full depth coarse aggregate method of repair utilizing a combat heavy engineer platoon under simulated tactical conditions. Actual aircraft gear loadings were used to provide performance data.

Test site - construction of craters

9. The Battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

10. The four craters that currently exist in the pad have been used in previous semiannual training exercises. Prior to the exercise conducted on 18 October 1979, crater 1 contained BN 25 concrete 12 in.* thick, and crater 3 contained a uniformly graded crushed stone aggregate. These were the two craters used for the exercise on 18 October 1979.

11. Crater 1 was broken open using a wrecking ball dropped from the bucket of a 5-yd loader and a D7 dozer with ripper teeth. A crater approximately 18 ft in diameter and 3 ft deep was constructed. Crater 3 was dug open by a D7 dozer. A crater approximately 75 ft in diameter and 5 ft deep was constructed. Both craters had heaved sections of concrete scattered about the edges as well as "in situ" material spread around the craters (Photo 2). Crater 1 also had approximately 1 ft of standing water in the bottom.

Backfilling and surfacing

12. Backfilling operations began as soon as the platoon arrived on site at 0845. A 5-yd loader immediately began to push select small ejecta (no size larger than 12 in.) into the crater (Photo 3). Shortly thereafter, a D7 dozer entered the hole to start spreading what the 5-yd

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page iii.

loader pushed in and compacting the fill (Photo 4). The 5-yd loader would also push all large heaved sections of concrete and unsuitable ejecta to the side of the runway (Photo 5). These two vehicles worked as a team. Both pieces of equipment were finished by 0957. The level in crater 3 was 24 in. from the level of the surrounding concrete. Concurrently, three 20-ton dump trucks were hauling in select fill (0-32 mm) material and stockpiling it next to crater 3. (Figures 5 and 6 show the sieve analysis data and grain-size distribution chart, respectively, of the select fill material). The first load arrived at 0912, and at 0955 eight loads had been stockpiled. At 1000, a 30-ton vibratory roller entered the large crater to compact the ejecta prior to select fill being added (Photo 6). The compacting lasted approximately 8 min with the 30-ton vibratory roller making two passes over the area. At 1008, the 5-yd loader and D7 dozer began pushing the stockpiled aggregate into crater 3 (Photo 7). Also, the 20 tons was now back-dumped directly into the crater rather than stockpiled (Photo 8). As the filling of the large crater was being accomplished, a 5-yd loader spread the aggregate uniformly over the area in a concave 12-in. lift (Photo 9). The concave lift ended at the surface of the existing concrete to allow the vibratory roller to enter the crater. The first lift of 12 in. was spread by 1025. A 30-ton vibratory roller, Tampo Model RS-28, then entered the crater and made four passes over the area (Photo 10). This took 15 min, until 1040. A quality control check was then made using a nuclear densimeter to obtain an average reading of 97.1 percent (Table 1). This was accomplished in 5 min. Then the second lift of 0-32 mm aggregate was placed as before. It was also compacted once again by the 30-ton vibratory roller covering the area four times. At this point, a Cat 120 road grader placed the final grade on the crater (Photo 11) as the second lift was placed 2-3 in. above the final grade. After the grader placed the final grade, the 30-ton vibratory roller went over the area twice. A final quality control check was made using the nuclear densimeter to obtain an average reading of 101.6 percent (Table 1). This completed the crater preparation at a time of 1210. (Total elapsed time being 3 hr 25 min.)

13. While all the operations described above were going on at the large crater site 3, the following was concurrently being accomplished at the small crater site 1. At 0900, six personnel with one noncommissioned officer (NCO) began preparing the small crater. Water was standing approximately 1 ft deep in the bottom, and it was bailed out with steel pots in 10 min (no pump was available during this test). The edges were then cleaned by a grader, which also removed all large ejecta and unusable ejecta to the side of the runway. Five personnel with shovels then spread the usable ejecta in the crater. Then, two vibrating plate compactors were used to compact the ejecta (Photo 12). One area was spongy as water was being forced up. Progress continued with no action being taken to correct the water problem. Uniformly graded aggregate was then added to the crater by back-dumping a 20-ton load of 0-32 mm aggregate. A grader spread the aggregate and a 30-ton vibratory roller compacted it making four passes. A nuclear densimeter reading then was obtained (Table 1). Next, the second and third lifts were added, spread, and compacted with nuclear densimeter readings being obtained.

14. Back at the large crater site 3, a sand blot method utilizing liquid asphalt and sand was being applied to one half of the crater (to keep foreign object debris down). Prior to spraying the liquid asphalt, the asphalt kettle pipes had to be warmed. The mixture (called haftkleber) was then applied uniformly over one half of the crater (Photo 13). The approximate rate was 0.2 gal/sq yd. Sand was then spread over the newly sprayed area. A grader was first used to spread the sand, but it left the area too thick in sand. Next, a rotary sweeper was applied to scatter the sand, but this method did not work as the controls of the sweeper did not have enough fine tuning. It was eventually spread by shovel, which turned out to be the easiest and fastest.

15. Two pieces of equipment were utilized to clear the runway: (a) the grader (when not being used to spread aggregate) cleared the heavy debris, and (b) the rotary sweeper pulled by a 5-ton tractor (M52A2) cleaned the remaining runway surface (Photo 14). The sweeping took approximately 1-1/2 hr but was interrupted numerous times.

Trafficking of test craters

16. A load cart (Photos 15 and 16) was used to simulate the wheel load of an F-4 aircraft. The total weight over the F-4 wheel was 25,500 lb with tire pressure equalling 286 psi. The first pass of the load cart over the small crater site 1 was made to see if it would operate properly. After two passes, the deflection was from 3 to 4 in. deep (Photo 17). The load cart was then taken up and positioned in the center of the large crater site 3. It was passed 30 times across the crater with deflections of 3 in. (Photo 18) after 20 passes and 4 in. (Photo 19) after 30 passes.

17. A test strip was then recompacted approximately 8 ft away by passing the 30-ton vibratory roller across 28 times. A nuclear densimeter reading was then taken yielding a compaction of 107.4 percent. The load cart was then passed 30 times across this area with a maximum deflection of 2 in. (Photos 20 and 21) in one spot. Most of the deflection was between 1/2 and 1 in. deep.

Analysis of results and conclusions

18. Analysis of results. Since the small crater had water in the subgrade that never was corrected, it was understandable that the load cart deflected the cap 4 in. after only two passes, even though a reading on the nuclear densimeter indicated 100 percent compaction effort (for 12-in. lifts only). On the large crater, the 4-in. deflection after 30 passes was unexpected. It is obvious that many more passes are needed by the 30-ton vibratory roller to achieve even minimum satisfactory results (as indicated, the 28 additional passes, plus the original four, produced a maximum deflection of 2 in. in one spot).

19. Conclusions. It was concluded that:

a. If any water exists in the crater, it must be removed.

b. More compaction effort is required: just achieving 100 percent is not good enough.

c. Spreading sand on liquid asphalt must be done by hand using shovels and brooms.

d. Sweeping of runway must be continuous, throughout the exercise.

e. The 0-32 mm aggregate does not specify the detail of gradation. In the locally available 0-32 mm aggregate, additional sand size particles in the No. 4 to No. 40 sieve size are needed to obtain higher densities.

Table 1

RERЕPS Density Tests (18 October 1979)

Test No.	γ_d	% Compaction	Test No.	γ_d	% Compaction
1	118.69	98.1	9	110.72	91.5
2	118.45	97.9	10	122.80	101.5
3	116.79	96.5	11	121.94	100.8
4	123.78	102.3	12	116.0	95.9
5	122.63	101.3	13	122.94	101.6
6	123.11	101.7	14	124.84	103.2
7	120.12	99.2	15	129.96	107.4
8	121.78	100.6			

Reading Time/Test - 2 min   Testing Depth - 6 in.

Remarks

Material tested was 0-32 mm fill. Maximum dry density was 121 pcf. Water content was estimated at 2.75 percent. Tests 1 through 5 were done on the small-size crater. Tests 1 and 2 were taken on the bottom layer in the small-size crater, and tests 3 and 4 on the upper layer. Test 5 was taken on the top, finishing layer.

Compaction value for the bottom layer in the small-size crater was 98 percent; for the upper layer, 99.4 percent; and for the top, finishing layer, 101.3 percent. The roller made 8 passes over the bottom layer and 16 over the upper layer.

Test 6 was done on the finished surface of the smallest crater. Tests 7 through 15 were done on a large-size crater. Tests 7 through 9 were conducted on the bottom layer in the large-size crater, and tests 10 through 13 on the upper layer. Compaction value for bottom layer in large-size crater was 97.1 percent.

Test 14 was a retest of the upper layer after further compaction, bringing the compaction value up to 101.6 percent. Test 15 was a retest of the upper layer in the large-size crater on an area over which the roller had made 32 passes.

Soils Technician
SP4 Michael Iezzoni

SIEVE ANALYSIS DATA

DATE 31 October 1979		
PROJECT REREPS	**EXCAVATION NUMBER**	**SAMPLE NUMBER**
DESCRIPTION OF SAMPLE 0-32 mm material of grayish color		**PREWASHED** [X] YES [ ] NO
WEIGHT ORIGINAL SAMPLE (gm.) 2167.5	**WEIGHT AFTER PREWASHING¹ (gm.)** 2078.5	**WASHING LOSS¹ (gm.)** 89

SIEVE OR SCREEN a	WEIGHT RETAINED ON SIEVE (gm.) b	PASSING SIEVE WEIGHT (gm.) c	PASSING SIEVE PERCENT d
* 1-1/2 in.	0	2172	100
1 in.	255	1917	88.25
1/2 in.	570	1347	62
3/8 in.	269	1078	49.6
No. 4	450	628	28.8
No. 10	238	390	17.95
No. 20	132.5	257.5	11.85
No. 40	67	190.5	8.8
No. 60	39	151.5	6.9
No. 100	32	119.5	5.5
NUMBER 200	25.5	94	4.3

A. WEIGHT SIEVED THROUGH NO. 200 (gm.) 5	**ERROR (Original weight - total weight of fractions)(gm.)** 2167.5 - 2162 = 5.5
B. WASHING LOSS¹ (gm.) 89	
TOTAL PASSING NO. 200 (gm.) (A + B) 94	**PERCENT ERROR** $\left(\frac{\text{Error (gm.)}}{\text{Original weight (gm.)}} \times 100\right) = 0.25\%$
TOTAL WEIGHT OF FRACTIONS (Total of all entries in Col. b) (gm.) 2172	

REMARKS

% Gravel = 71.2
% Sand = 24.5
% Fines = 4.3

Cu = 2.5
Cc = 3.1

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
SP4 Michael Iezzoni	SP4 Michael Iezzoni	

¹For prewashed samples only. *Maximum particle size.

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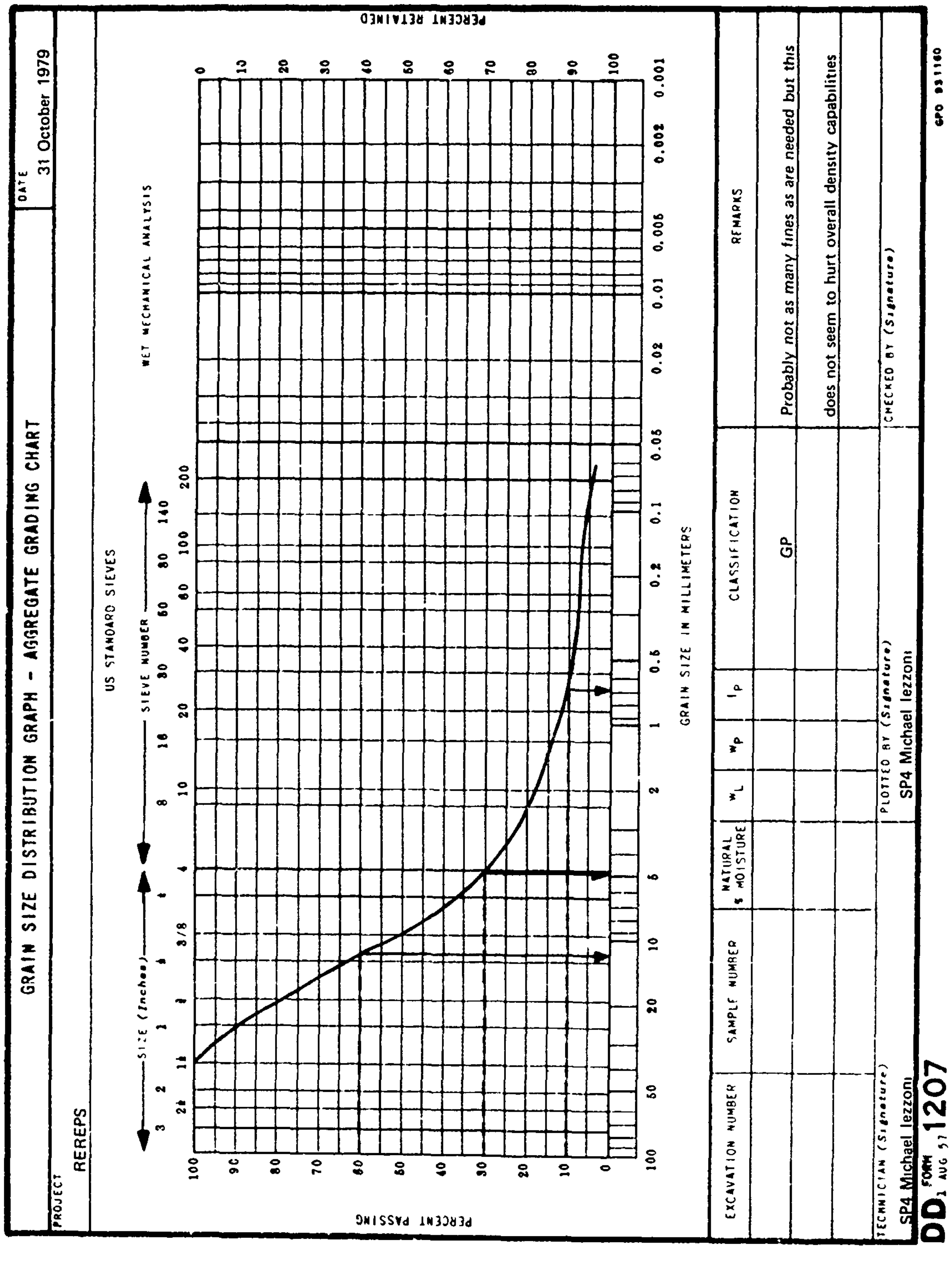
Figure 5



GRAIN SIZE DISTRIBUTION GRAPH - AGGREGATE GRADING CHART
PROJECT
REREPS
DATE
31 October 1979
US STANDARD SIEVES
SIZE (Inches)
SIEVE NUMBER
WET MECHANICAL ANALYSIS
PERCENT PASSING
PERCENT RETAINED
GRAIN SIZE IN MILLIMETERS
EXCAVATION NUMBER
SAMPLE NUMBER
NATURAL % MOISTURE
CLASSIFICATION
GP
REMARKS
Probably not as many fines as are needed but this
does not seem to hurt overall density capabilities
TECHNICIAN (Signature)
SP4 Michael Iezzoni
PLOTTED BY (Signature)
SP4 Michael Iezzoni
CHECKED BY (Signature)
DD FORM 1 AUG 57 1207

Figure 6

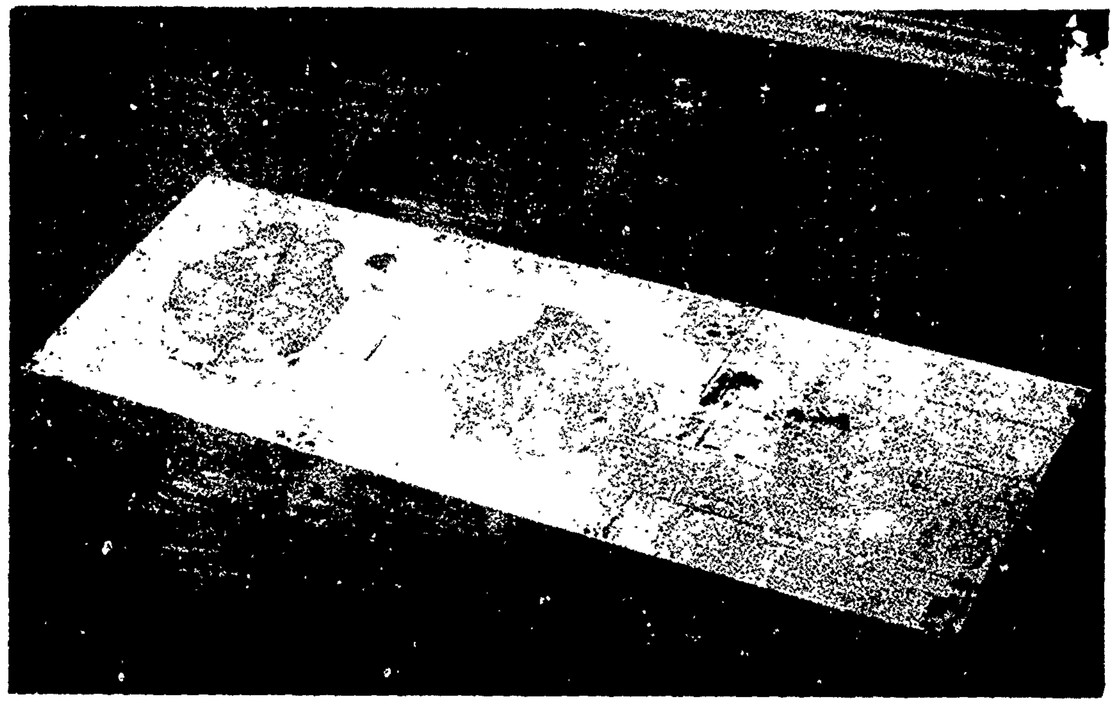


Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

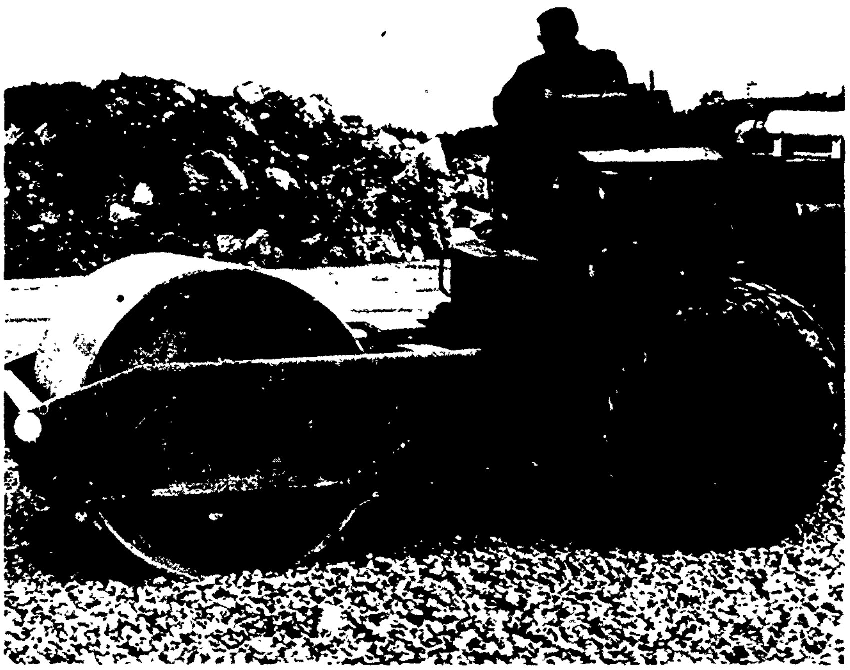


Photo 6

Photo 7

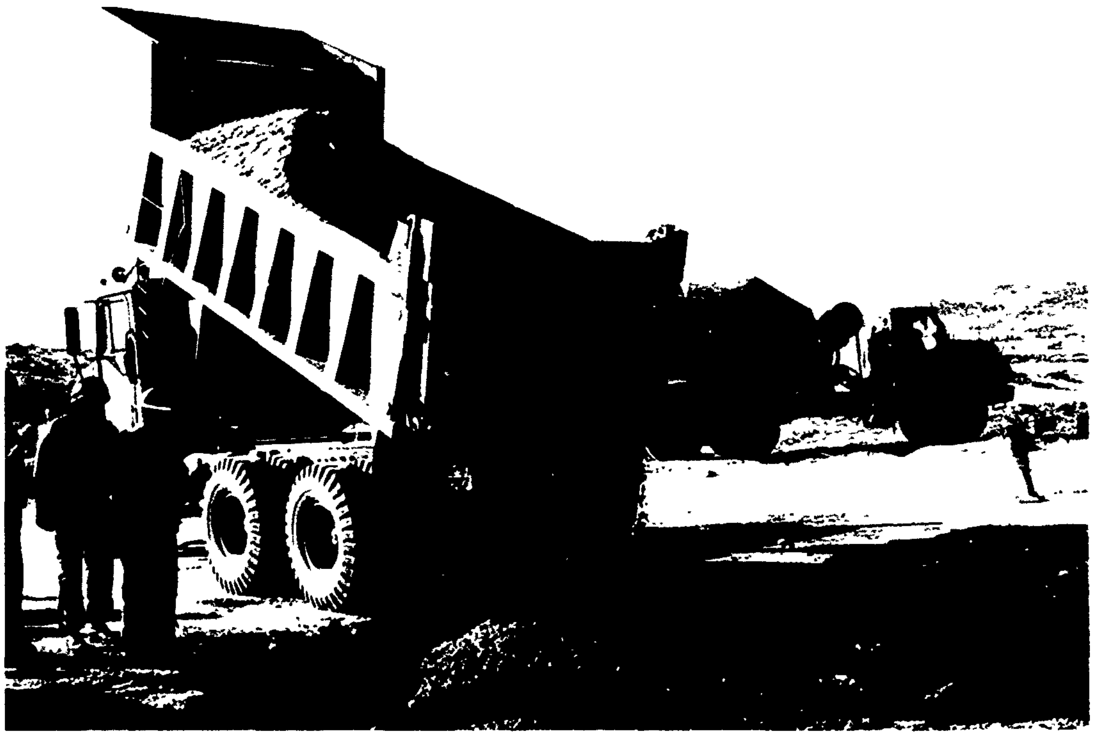


Photo 8

Photo 9

Photo 10

Photo 11

Photo 12

Photo 13

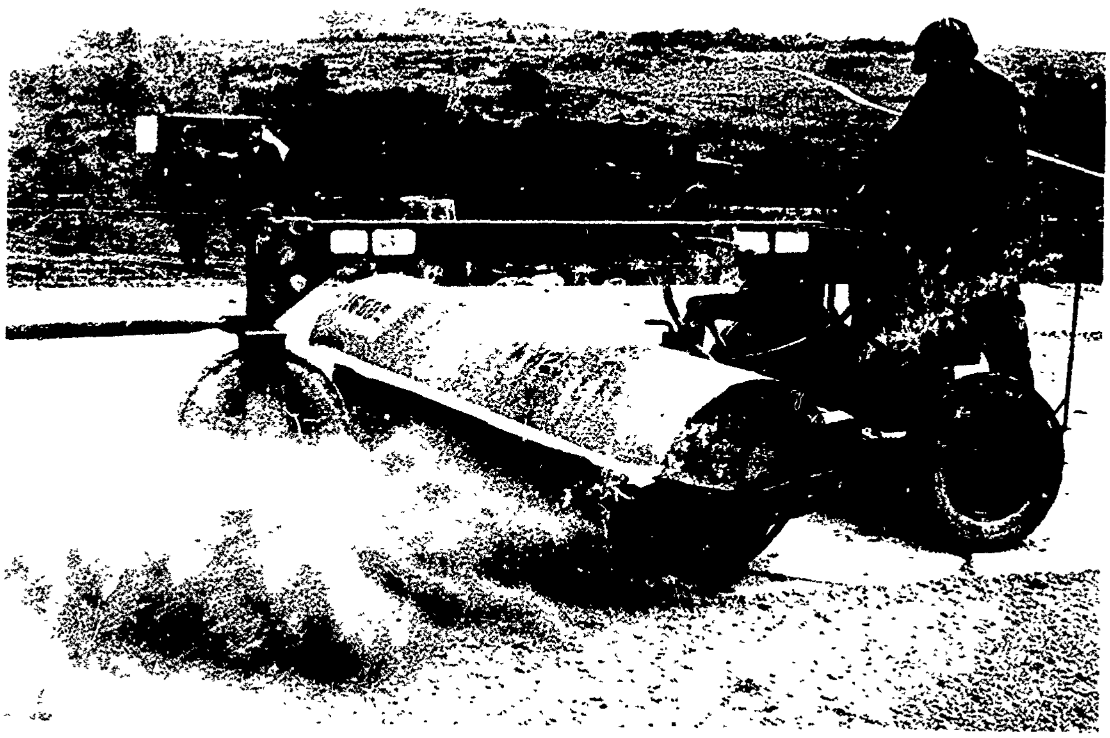


Photo 14

Photo 15

Photo 16

Photo 17

Photo 18

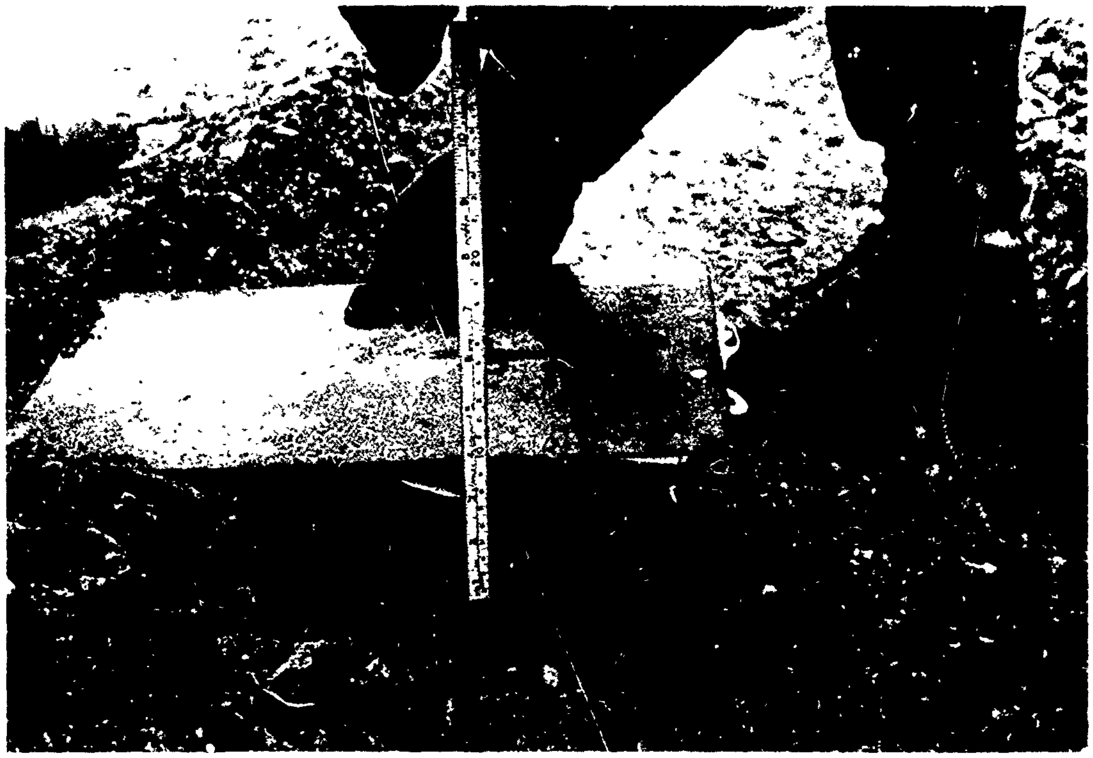


Photo 19

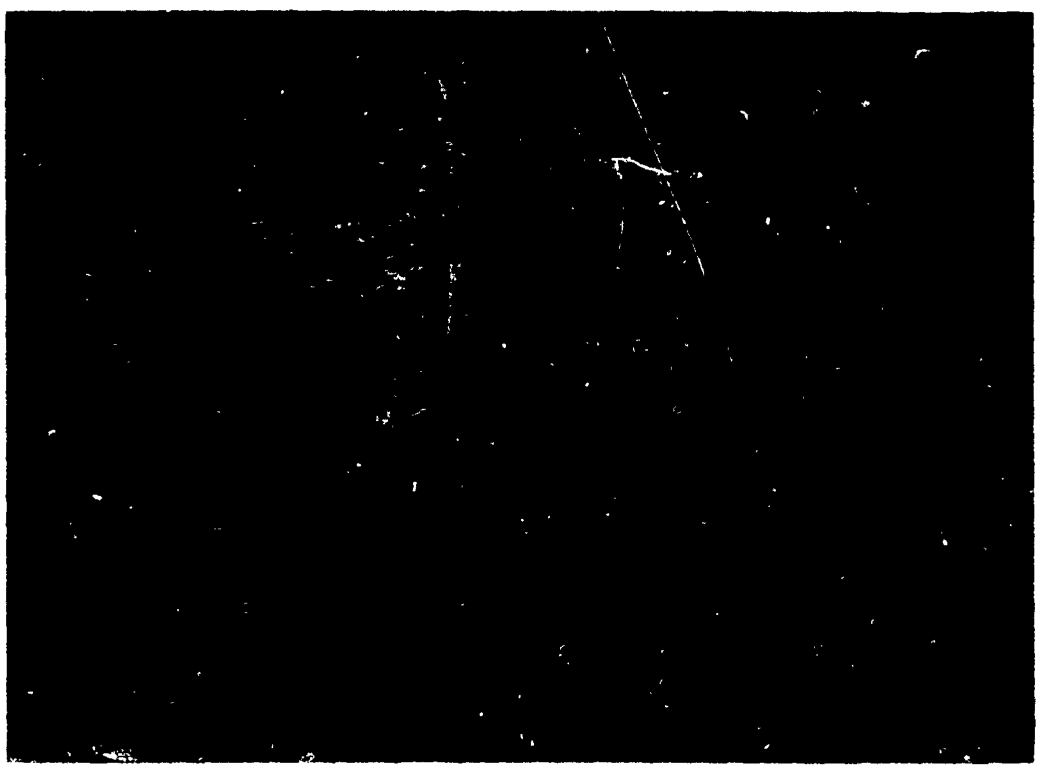


Photo 20

Photo 21

BN 25 Ready-Mix Concrete for Small Craters

Purpose

20. The purpose of this field test of project REREPS was to evaluate the repair of a small crater (less than 20 ft in diameter) utilizing a 12-in. concrete cap. This unit has conducted numerous field tests of large craters (40-70 ft in diameter) utilizing concrete, but never on smaller ones. Another purpose was to train new troops on the method employed and to retain proficiency in the technique. A final purpose was to evaluate which method should be used to bring the subgrade up to final grade in the most efficient manner.

Test site - construction of craters

21. The Battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

22. The four craters that currently exist in the pad have been used in previous semiannual training exercises. Prior to the exercise conducted on 23 October 1979, crater 1 contained a uniformly graded crushed stone aggregate. This was the crater used for the exercise.

23. Crater 1 was dug using a backhoe, John Deere Model JD410. A crater approximately 23 ft in diameter and 3-4 ft deep was constructed. The crater had "ejecta" spread around it. Crater 1 also had approximately 1 ft of standing water in the bottom (Photo 22).

BN 25 concrete repair

24. Backfill. At 0900, a 5-yd loader began clearing the unusable ejecta (larger than 12 in. in size) from around the crater and also a path for the truck-mounted water pump (Photo 23). At 0915, the pump truck backed up to the crater and began to pump the in-place water out. This operation lasted approximately 10 min. (Some amount of handwork with shovels was done to free trapped pockets of water so that all the water could be pumped out.) Starting at 0930, the remaining usable ejecta (smaller than 12 in.) was pushed into the crater. The 5-yd

loader then tried to level the backfill in the crater but was not successful because it was too large for that size crater.

25. At 0935, a towed 7.5-ton vibratory roller pulled by an M52A2 5-ton tractor was backed into the crater to try to compact the fill (Photo 24). However, it bogged down because there was too much soft ejecta in the crater. Then, a backhoe, John Deere Model JD41C, tried to clear some of the ejecta back out of the crater (Photos 25, 26, and 27). This method proved to be a slow process, so at 1015 it was discontinued. The 5-yd loader then moved back to the crater and took some of the ejecta back out as there was still too much in the crater. At 1026, after the roller had been repaired, it was again backed into the crater to begin compacting the ejecta. This continued for 20 min. During this time also, personnel used two whacker tampers to compact around the edges of the crater (Photos 28 and 29). Personnel also removed any loose pieces of concrete from around the crater edges (Photo 30). After the compacting was complete, a quality control check was made using a nuclear densimeter to obtain a reading of 86 percent CE 55 (Photo 31 and Table 2). (It must be pointed out here that a quality control check was not made to check the depth required from the existing level of the surrounding concrete to the level of the compacted ejecta, namely 36 in. Personal observation by this officer reflects that it was only 24-30 in.)

26. At 1050, a 20-ton dump truck back-dumped a load of 0-32 mm aggregate into the crater (Photo 8). (Figures 5 and 6 show the sieve analysis and grain-size distribution chart, respectively, of the select fill material.) The 5-yd loader then leveled the fill. The towed vibratory roller then was backed into the crater to compact the first lift. This was completed at 1112. Again hand tampers were used to compact around the edges. A quality control check was made, resulting in a 95 percent compaction. Since the platoon had only one loader and one 20-ton truck that day, both had to go back to the quarry for another load of 0-32 mm aggregate. After they were gone about 30 min, the S-3 officer on site suggested that usable fill could be obtained from the side of the runway. This was accomplished, and the final lift was

placed and compacted by 1150. (The quality control check showed a 95 percent CE 55.) When this was done, a 250-cfm air compressor cleared the edges of the crater and 2-3 ft around the crater using compressed air (Photo 32). At 1158, a 5-yd loader and a CAT 120 road grader pulled the screed beam to one side of the crater (Photo 33).

27. Surfacing. The first truck placed its load of concrete (5 cu m) at 1202, just 2 hr after being ordered (Photo 34). The second truck arrived at 1208 and placed its load of concrete (Photo 35). The screed beam was then passed over crater by having the grader hold one edge with its blade, while the 5-yd loader pushed the screed beam across the crater. Since the estimate on the size of the crater was inadequate, not enough concrete was ordered. Another truck was then ordered, and it arrived at 1250. The screed beam was passed two more times over the crater. Finally, the crater was floated using handmade wooden floats (Photo 36). Floating was completed at 1323. One should observe that the edges were not floated well enough to tie into the original surrounding pavement (note that the concrete cap was 12 in. thick). Compressive strength tests were made on a sample of the concrete used at 7-, 14-, and 28-day intervals (Figures 7, 8, and 9, respectively).

28. Runway cleanup. Runway cleanup consisted of a CAT 120 road grader scraping the large debris from the runway surface and a towed rotary sweeper pulled by a 5-ton tractor to clean the fine debris (Photo 37). The cleanup lasted approximately 3 hr, with stops throughout.

Trafficking of test crater

29. Load cart. A load cart (Photos 15 and 16) was used to simulate the wheel load of an F-4 aircraft. The total weight over the F-4 wheel was 25,500 lb with tire pressure equalling 286 psi.

30. Application of traffic. The load cart was passed over the concrete cap 30 times in the same lane 7 days after being placed. The vehicle was guided by two personnel, one in front and one in back. The vehicle was backed over the cap so that the F-4 wheel exerted pressure.

31. Behavior of test crater. There were no deflections in the concrete cap after 30 passes. It was noted though that the edges were starting to break up slightly. This was not the result of the load

cart, but rather the poor finishing work done when the cap was floated.

Analysis of results and conclusions

32. Analysis of results. The repair of a small crater (less than 20 ft in diameter) presents several problems. First, most of our equipment is too large to be effectively used. We are used to repairing large craters where our equipment can be effectively used. Second, there is no definite technique outlined, although we basically followed the same steps as we would use in repairing a large crater. As evidenced by the operation, there appears to be little time difference between a small and large crater repair, although since this is our first time, we have many improvements that can be made. Third, the screed beam used was again originally designed for a large crater. It also tied up two very key pieces of equipment, the 5-yd loader and the grader. Another method to screed the concrete flush must be employed. Fourth, there were problems with the concrete delivery. Only 10 cu m was ordered, and 15 cu m was needed. (That was our problem.) However, the second truck did not arrive on site until 2-1/2 hr after being ordered. Had the platoon been ready earlier, valuable time would have been wasted waiting for concrete. Fifth, there is an optimum delivery time, as well as planned spacing of the concrete trucks around the crater, to speed up the operation. One method to employ is to have all the concrete on hand 15 min prior to placing and the trucks back up to the crater from the same direction. Then, when they place their concrete, they can form a head in front of the screed beam and move forward as the surface is screeded flush. Sixth, the platoon did not adhere to the criteria in the amount of ejecta to push into the crater (i.e., they did not measure the depth of the crater from the existing runway surface; thus, when they had to dig some out, they were delayed even further).

33. Conclusions. Since the art of repairing small craters is not as developed as repairing large craters, hard and fast conclusions cannot be drawn. However, there are obvious conclusions that can be made which should be examined to improve small-crater repair techniques such as:

a. Smaller equipment is a must when working the small crater. A 2-1/2-yd loader does a much faster job in cleaning around the crater edge. Also, the towed airmobile vibratory compactor is the right size, but it is still awkward when backed by a 5-ton tractor.

b. There is a definite need for handwork. Five or six soldiers with picks, shovels, and hand tampers can do more than trying to utilize large equipment.

c. There is a definite need to develop a technique for small-crater repair.

d. There must be a capability to do multiple small and large craters simultaneously.

e. There is also a need to identify at what level the ejecta should be placed from the existing concrete prior to select aggregate or even concrete being added.

The 293rd Engineer Combat Battalion (Heavy) will continue to repair small craters using a variety of techniques in future ADR exercises to try to answer some of the questions/problems identified.

Table 2

RERÉPS Density Tests (23 and 25 October 1979)

Test No.	% w	γ_d	% Compaction
1	5.5	107.15	88.6
2	5.5	115.36	95.3
3	5.5	120.10	96.1
4	5.5	128.77	103
5	5.5	129.59	103.7

Reading Time/Test - 2 min   Testing Depth - 6 in.

Remarks

Tests 1 and 2 were conducted on 23 October, and tests 3, 4, and 5 on 25 October. Soil tested was 0-32 mm material. Water content at 5.5 percent was only estimated.

Test 1 was taken on the lower layer. Minimum required compaction value was 85 percent. Test 2 was taken on the upper layer. Minimum required compaction value was 95 percent. Crater on which tests 3, 4, and 5 were conducted was first filled all the way up to the surface.

Test 3 was taken on area that had not yet been finally compacted. Test 5 was taken on surface area over which a simulated plane tire had rolled 30 times.

Soils Technician
SP4 Michael Iezzoni

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Sample taken 23 October 1979 Concrete Strength Test Report

TO S-3
293rd Engr Bn
APO 09034

FROM Materials Testing Sec
293rd Engr Bn
APO 09034

DATE

CMT 1

Following are the results of test requested in CMY 1.

Type Test: Compressive

Date and time of test: 30 October 1979, 1430

The samples were laboratory cured by: N/A Site cured

The samples were capped with: Sulfur Compound on 30 October 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	7-Day Compressive Strength, psi
1	6	15,000	530.52

* r Compressive Strength Test, dimension is cylinder diameter.

Remarks: Result of this test is unusually low, showing extreme weakness in concrete after 7 days.

Analyst
SP4 Michael Iezzoni

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 7

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Sample taken 23 October 1979 Concrete Strength Test Report

TO S-3
293rd Engr Bn
APO 09034

FROM Materials Testing Sec
293rd Engr Bn
APO 09034

DATE

CMT 1

Following are the results of test requested in CMT 1.

Type Test: Compressive

Date and time of test: 6 November 1979, 0845

The samples were laboratory cured by: N/A Site cured

The samples were capped with: Sulfur Compound on 5 November 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	14-Day Compressive Strength, psi
1	6	34,000	1202.50

* For Compressive Strength Test, dimension is cylinder diameter.

Remarks: Result of this test indicates no significant increase in strength of concrete over 7-day test, considering the 14-day curing period.

Analyst
SP4 Michael Iezzoni

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 8

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Sample taken 23 October 1979 Concrete Strength Test Report

TO S-3
293rd Engr Bn
APO 09034

FROM Materials Testing Sec
293rd Engr Bn
A D 09034

DATE

CMT 1

Following are the results of test requested in CMY 1.

Type Test: Compressive

Date and time of test: 20 November 1979

The samples were laboratory cured by: N/A Site cured

The samples were capped with: Sulfur Compound on 19 November 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	28-Day Compressive Strength, psi
1	6	49,000	1733.02
2	6	44,500	1573.86
		Average	1653.44

* For Compressive Strength Test, dimension is cylinder diameter.

Remarks: This concrete has shown to be far below the expected rate of strength for all three of the testing periods.

Analyst
SP4 Michael Iezzoni

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 9

Photo 22

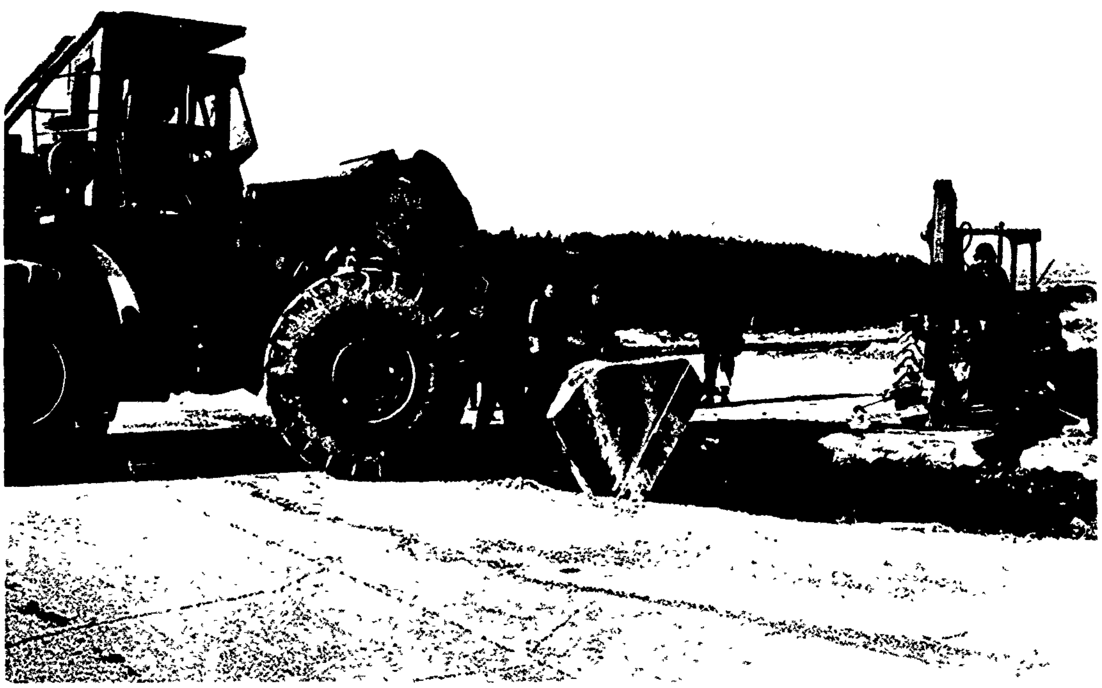


Photo 23

Photo 24

Photo 25

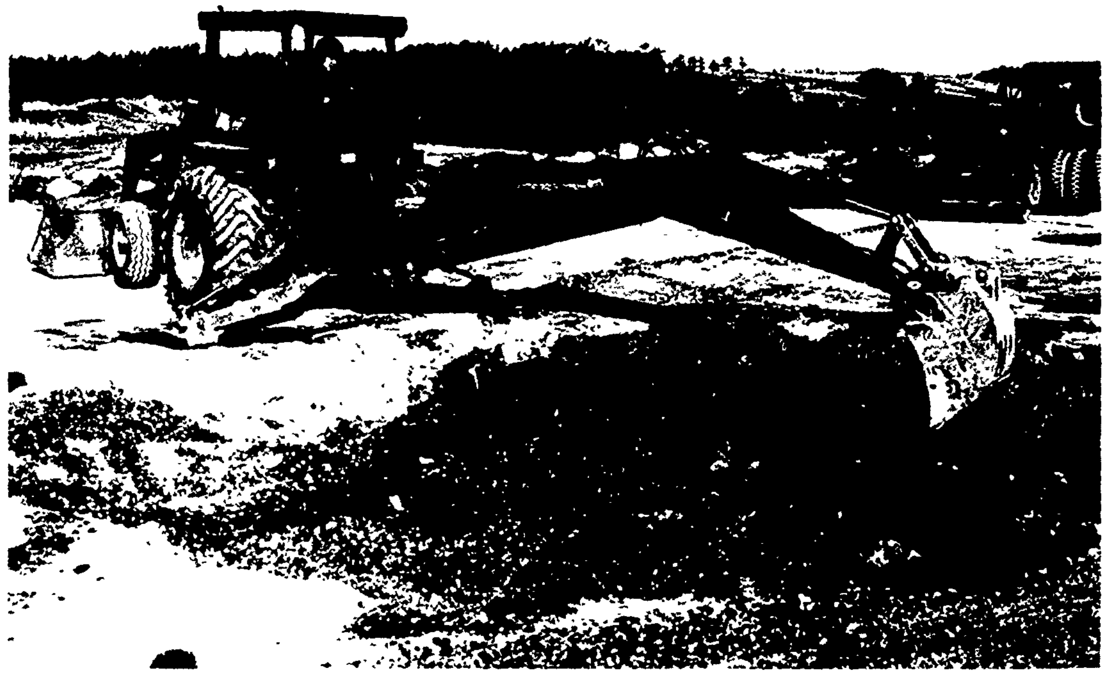


Photo 26

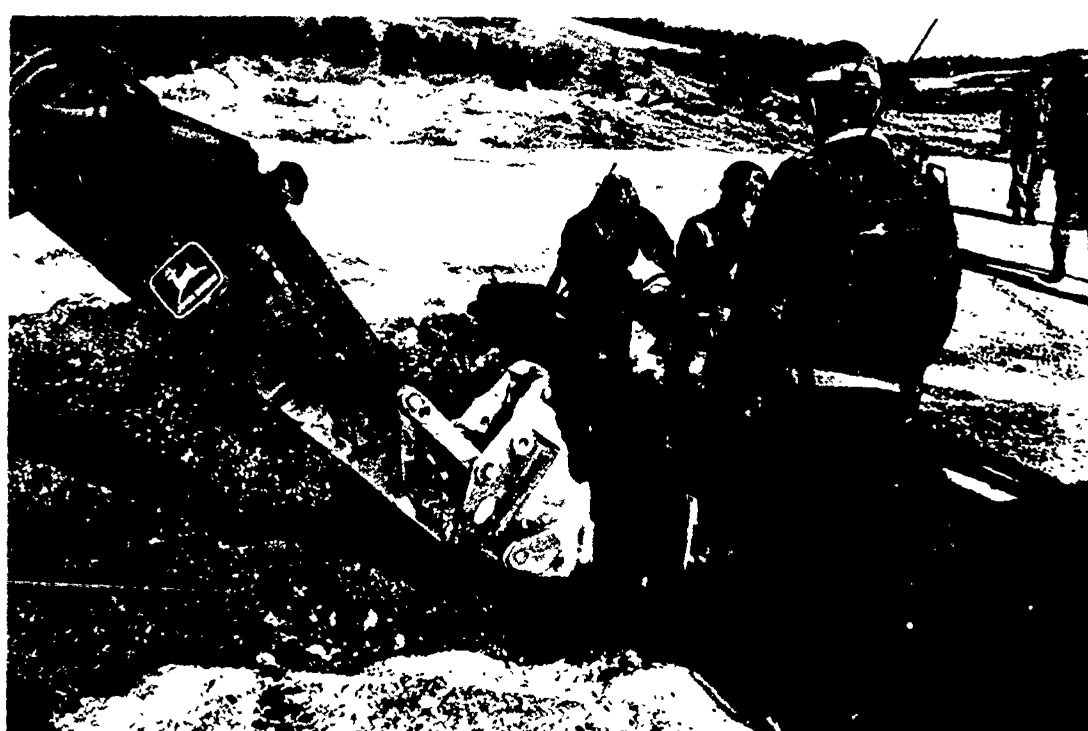


Photo 27

Photo 28

Photo 29

Photo 30

Photo 31

Photo 32

Photo 33

Photo 34

Photo 35

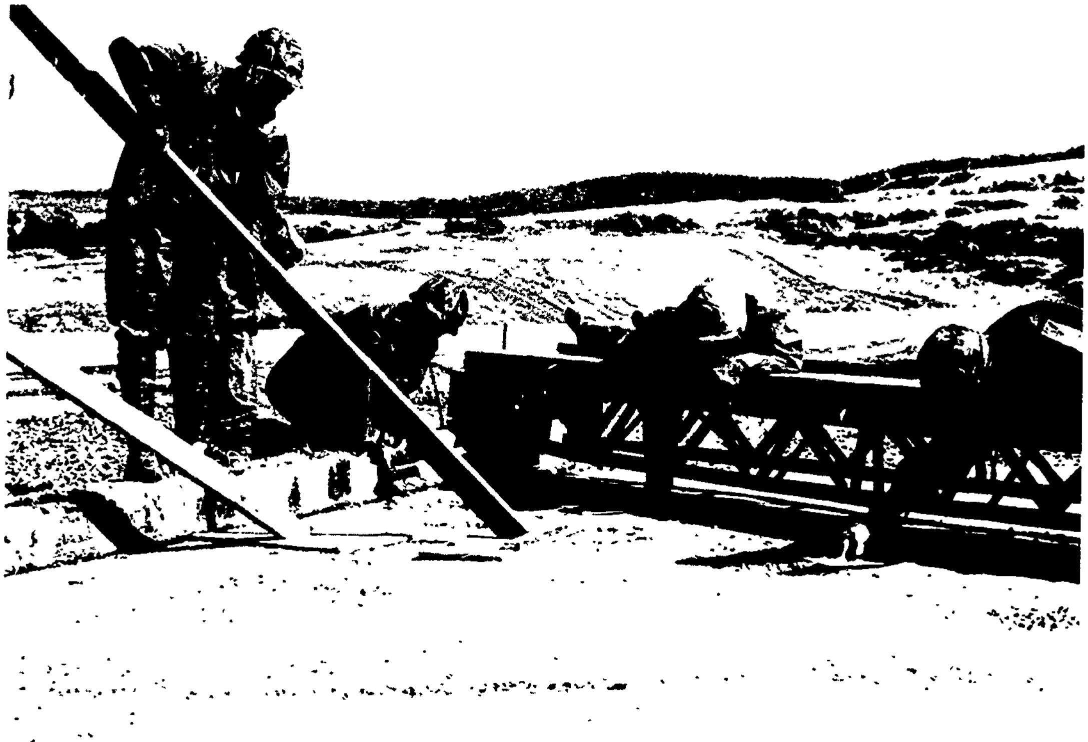


Photo 36

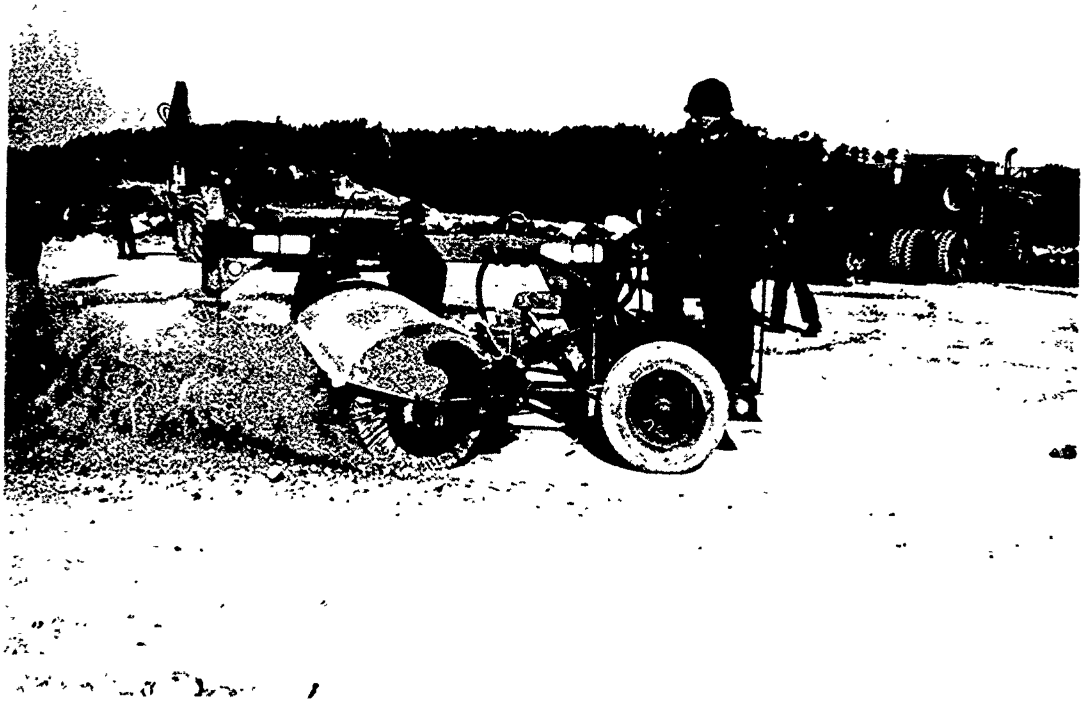


Photo 37

Spall Repair Using Concrete and Steel Plates

Purpose

34. The purpose of this field test of project REREPS was to evaluate the repair of spalls using concrete and steel plates. Another purpose was to evaluate the compatibility of using this method with the equipment organic to this unit. A further purpose was to provide an estimate of the time required to repair one of the spalls.

History

35. A spall is a hole in the runway surface that measures up to 1 m in diameter and does not penetrate through the runway to the base. The British Royal Engineers originated the idea and train employing the method. Their term for spalls is "scabs." Their repair procedure consists of the following four steps:

- a. The scab area is cleared of debris and swept clean.
- b. A steel plate is laid over the scab, overlapping to provide a good key for the Rawl bolts.
- c. A drilling and bolting crew, using four Kango hammer drills from a 6-kVA generator trailer, drilled holes in the pavement and bolted down the plates with Rawl bolts.
- d. The area is swept clean to remove any foreign object damage (FOD) hazard.

Time estimates given by the British to repair spalls this way are 7 min on a concrete pavement and 10 min on a bituminous pavement. The British also have three sizes of plates for various sized spalls (Figures 10, 11, and 12). Since they have found this method of spall repair to be satisfactory, they advocate its use.

Test site - construction of spalls

36. The Battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

37. The spalls were created by drilling holes in the concrete slab using a Davey 250-cfm air compressor and pavement drills. The spalls were approximately 0.15 m deep and 0.5 to 0.6 m in diameter (Photo 38).

Spall repair exercise

38. Methodology. The method employed was patterned after the British technique with one exception. We filled the spall with concrete first and then put on the steel plate, whereas the British simply put on the steel plate. We did this for one very conscious reason. The steel plate could then be removed after the concrete had cured and be reused. Doing this would also cut down on the number of small metal patches dotting the airstrip and possibly creating a hazard if they were ripped loose by repeated takeoffs and landings.

39. Concrete. The spall exercise commenced at 0930. (Note that it was part of the exercise to repair a small crater with concrete on 23 October 1979.) The first thing that was done was to clean out the spall and the surrounding area. This was accomplished by first running a rotary broom sweeper towed by an M151A2 jeep over the spall area, then followed by blowing the small debris in the spalls out with compressed air from a Davey 250-cfm air compressor.

40. Concrete was mixed by hand in a wheelbarrow using a standard mix design of one part cement, two parts sand, and three parts stone, and then adding water in small amounts to obtain a workable mix. Next, the concrete was placed in the spalls by shovel, flush to the existing concrete surface, and floated even.

41. Steel plates. The steel plates were then placed over the spalls. A starter hole was then made in the concrete using a Black and Decker drill with a small masonry bit (Photos 39 and 40). (Drill characteristics - 115 V, 6 Hz, and 100 Amp at 375 rpm; bit characteristics - Stein Bohrer masonry drill bit, 0-16 mm or 5/8 in.) The drills were powered by a 4-kW generator, which is mounted in the back of a second echelon maintenance (SECM) contact truck. (Generator characteristics - 4 kW, 120 V, and 60 cycles with a power factor of 1.) A larger drill bit (25 mm or 1 in.) was then used to drill the holes into the concrete. (Note that the steel plate was removed to do this.)

42. It was discovered at this time that drilling the holes was not as easy as everyone had thought. To drill four holes for one of the steel plates took almost 1 hr. After the holes were drilled, a metal

expansion anchor was driven into the hole. The purpose of the expansion anchor was to receive and secure the bolt in the concrete.

43. The steel plate was then placed over the spall again, and the holes in the plate and concrete were lined up. The bolts were then screwed into the holes and tightened with allen head sockets on a socket wrench. (Note that the holes did not match exactly, and one bolt was not placed flush with the steel plate but was slightly raised at an angle above the plate.)

44. The final step of the exercise was to clean around the spalls for FOD removal. This was accomplished by a rotary sweeper. The exercise ended at 1100, exactly 2 hr after starting. (Note that only two steel plates were put down.)

Analysis of results and conclusions

45. Analysis of results. Several problems were encountered with placing the steel plates. The first and most obvious is that it took 1 hr to drill four holes in the concrete surface. This is not consistent with the British time of 7 min and 10 min, respectively, to place the plate and bolt it down. The problem is possibly with the bits and drills that we used. The drills were the standard drills found in a general construction platoon and were possibly not heavy duty enough. The drill bits were considered the best available masonry bits. Another problem was deciding how far the hole should be drilled. For example, one hole was not drilled far enough so that when the anchor was driven, it stuck up over the concrete surface; then one was driven too far, thereby allowing the bit to be driven in too far. A possible solution is to mark the drill bit with a line for controlling the depth of the hole. The last problem encountered was lining up the holes and making them match. One hole did not exactly match causing the bolt to stick above the plate when tightened down as far as it would go.

46. Conclusions. The conclusions that were reached from the exercise are:

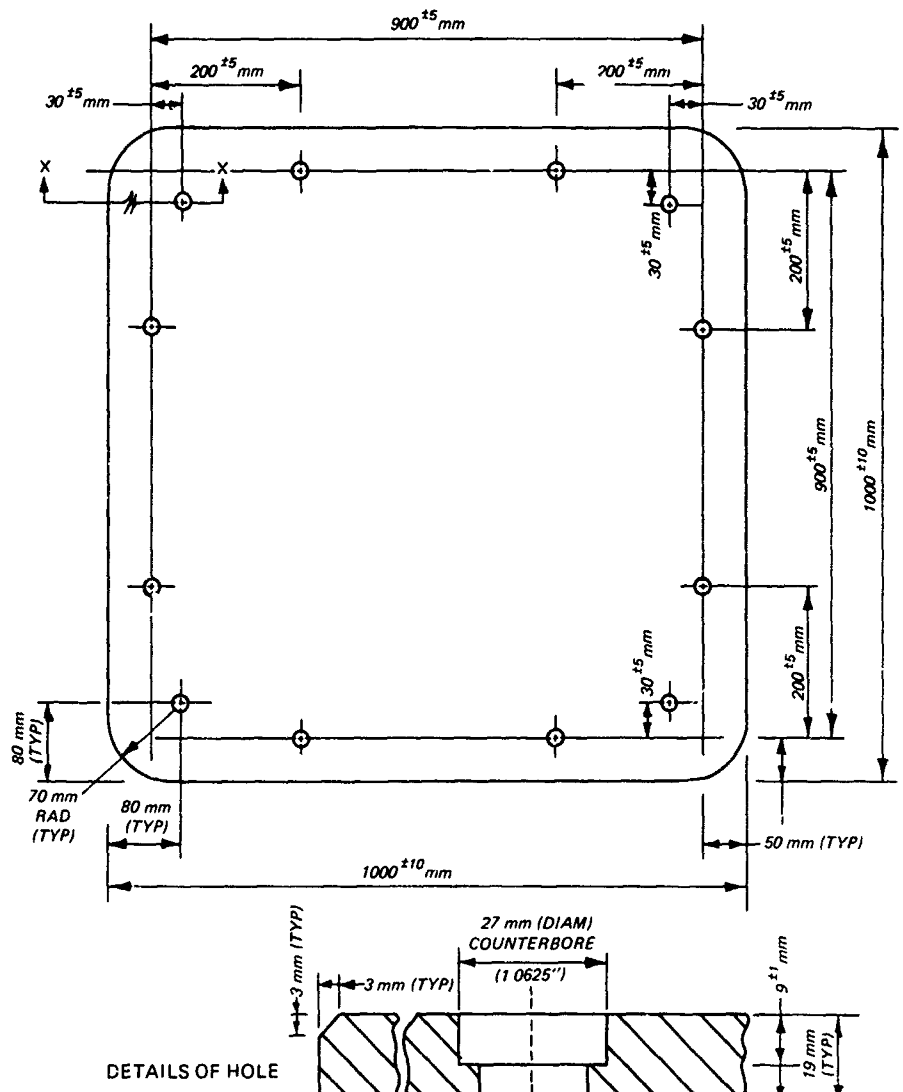
a. This method takes too long for the equipment that we organically own.

b. To be a satisfactory solution to spall repair, the time must be kept under 15 min per spall.

c. More research needs to be done spelling out specifics for optimum bolt size, anchor size, and number of holes per plate.

The 293rd Engineer Combat Battalion (Heavy) will continue to look into the feasibility of utilizing steel plates after obtaining more data from the British.

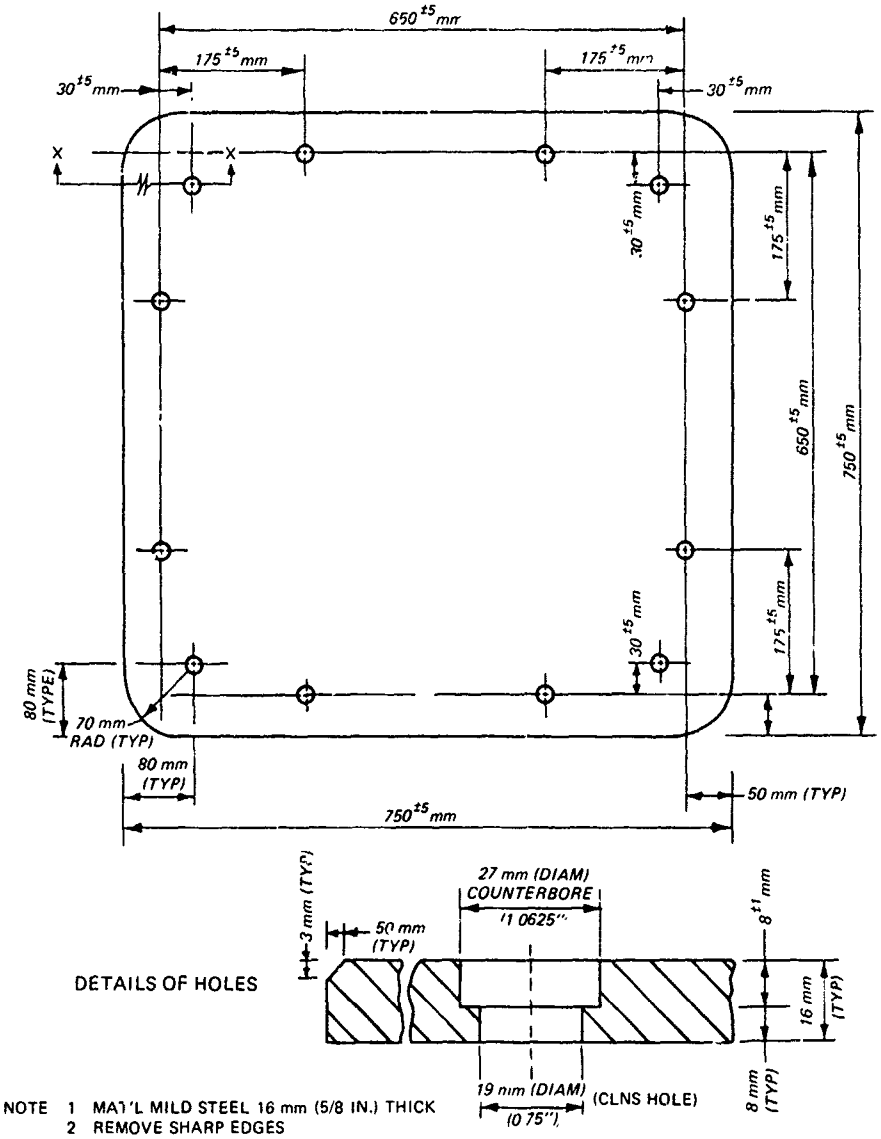
SCAB PLATE-LARGE



NOTE
1. MAT'L MILD STEEL 19 mm (3/4 IN) THICK.
2. REMOVE SHARP EDGES.
3. PLATE TO BE SQUARE.
4. EDGES MAY BE GUILLOTINE OR FLAME CUT

Figure 10

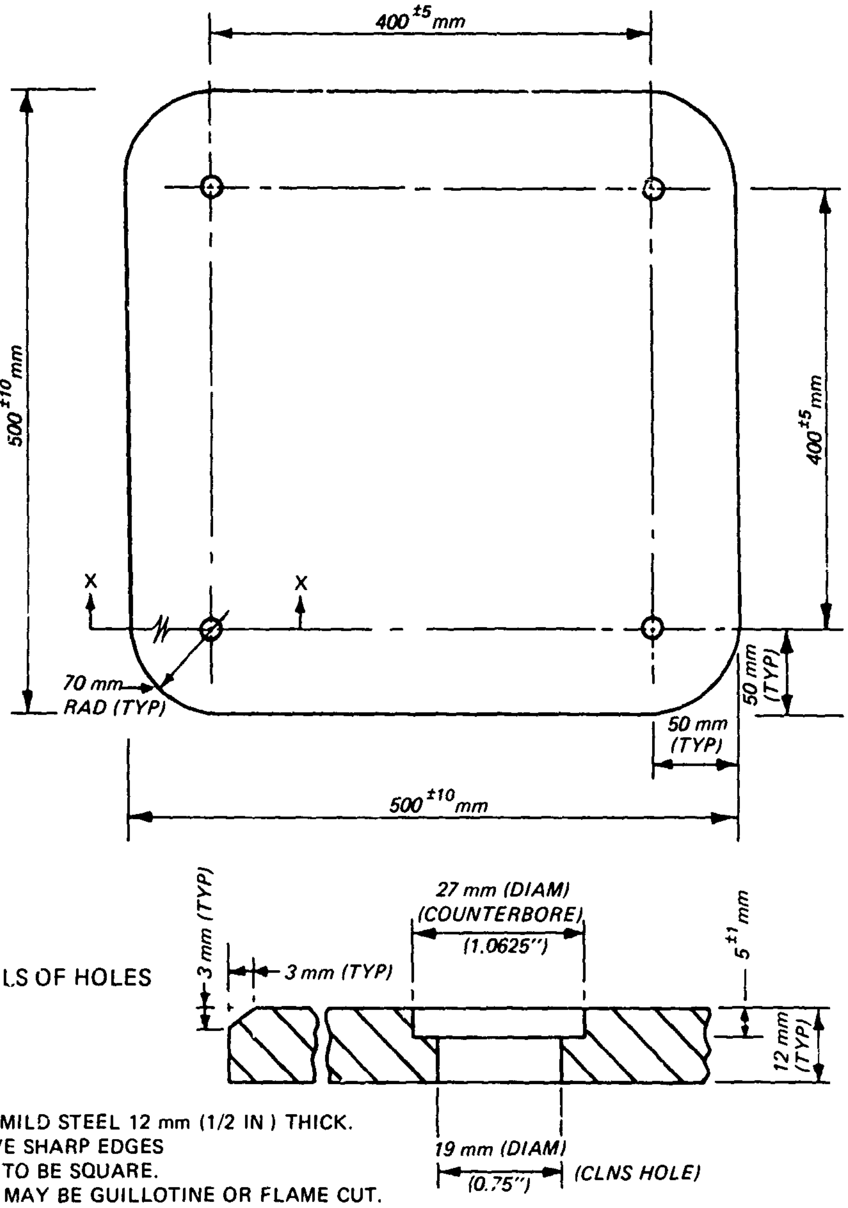
SCAB PLATE-MEDIUM



NOTE 1 MAT'L MILD STEEL 16 mm (5/8 IN.) THICK
2 REMOVE SHARP EDGES
3 PLATE TO BE SQUARE
4 EDGES MAY BE GUILLOTINE OR FLAME CUT

Figure 11

SCAB PLATE-SMALL



NOTE: 1. MAT'L MILD STEEL 12 mm (1/2 IN.) THICK.
2. REMOVE SHARP EDGES
3. PLATE TO BE SQUARE.
4. EDGES MAY BE GUILLOTINE OR FLAME CUT.

Figure 12

Photo 38

Photo 39

Photo 40

Crushed Stone (Air Force Technique)

Purpose

47. The purpose of this field test of project REREPS was to evaluate the technique in two ways. The first was to determine if the technique was suitable for troops using current equipment on hand. The second was to determine the reliability of the crater repair under simulated aircraft loading conditions. A combat heavy engineer platoon performed the repair under simulated tactical conditions. The exercise was also performed at night.

Methodology

48. The methodology for the crater repair was taken from an interim report (No. ESL-TR-79-01) published by the Engineering and Services Center at Tyndall Air Force Base, Florida. The title of the report is "Interim Field Procedure for Bomb Damage Repair - Using Crushed Stone for Crater Repairs and Silikal^{R} for Spall Repairs" and was written by Michael T. McNerney. The report period covered the months from June 1978-March 1979 and was published in April 1979.

Test site - construction of test crater

49. The Battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

50. Four craters currently exist in the pad, and they have been used in previous semiannual training exercises. Prior to the exercise conducted on 25 October 1979, crater 4 contained a uniformly graded crushed stone aggregate. This was the crater used during the test.

51. Crater 4 was dug out using a D7F bulldozer. It was approximately 23 m in diameter and 2.5 m in depth. There was no water in the crater. The crater had heaved sections of concrete and "in situ" material scattered about the crater edge (Photo 2).

Repair using crushed stone

52. Crater preparation. Crater preparation started as soon as a sweep to detect any unexploded ordnance was accomplished. The sweep was

conducted by the advance party using mine detectors, both metallic and nonmetallic. At 1950, just 5 min after the platoon's main element arrived on site, a 5-yd scooploader began to push select small ejecta (no size larger than 0.3 m) into the crater (Photo 41). Shortly thereafter, a D7F dozer entered the crater to start spreading what the 5-yd scooploader pushed in. The D7F dozer also compacted the ejecta by traversing back and forth across the crater as it spread the ejecta (Photo 4). The 5-yd scooploader would also push all large, heaved sections of concrete and unsuitable ejecta to the side of the runway (Photo 5). These two vehicles worked as a team. They completed this task at 2055. The depth below the existing concrete runway surface was now 0.6 m. (This was verified by extending a stringline across the center of the crater and measuring from the stringline to the level of the ejecta.) It must be mentioned here that a Cat 120 road grader assisted the 5-yd scooploader on one side of the crater to push unsuitable ejecta to the side of the runway. This was the platoon leader's idea to see if the operation could be sped up any. Little time was gained, if any, because the 5-yd scooploader finished well before the D7F dozer. Had the grader not assisted, they would have finished together.

53. Backfill. As the crater preparation was being accomplished, select aggregate material (0-32 mm) was being stockpiled near the crater. (Figures 5 and 6 show the sieve analysis and grain-size distribution chart, respectively, of the select fill material.) Twenty-ton dump trucks hauled in the fill from a large stockpile approximately 10 km away. The first loads of fill arrived at 2000. A total of 500 metric tons were hauled in. Hauling was completed at 2130.

54. As soon as the crater preparation was completed at 2055, the same 5-yd scooploader and D7F dozer began to push the stockpiled aggregate into the crater. Once enough aggregate had been pushed into the crater, the D7F dozer reentered the crater to start spreading the aggregate. The 5-yd scooploader remained, pushing the stockpile into the crater. As the stockpile was soon exhausted, the 20-ton dump trucks began to back-dump directly into the crater (Photo 8). This operation continued until 2150, at which time the crater was approximately

0.15-0.20 m above the existing runway surface. Since the area was very rough, a grader leveled the aggregate to 0.15 m above the runway surface. This was completed at 2225.

55. Surfacing. Once the aggregate surface was leveled to the correct height above the runway surface, the 30-ton vibratory roller started to make its passes across the crater (Photo 10). The crater was divided into lanes, each the width of the roller, minus 0.15 m for overlap. The roller commenced at 2230 and finished at 2250. The roller made four passes per lane. At this time, a density check was made using a nuclear densimeter (Photo 31). A value of 96.1 percent CE 55 was obtained (Table 2). Following this density check, the Cat 120 road grader made a final cut bringing the aggregate level to 0.03 m above the concrete runway surface. The grader started at 2250 and finished at 2310. Once the final cut was accomplished, the 30-ton vibratory roller made an additional 28 passes over each lane of the crater. The roller commenced at 2310 and finished at 0115. A density check was again made obtaining a reading of 103 percent CE 55 (Table 2).

56. Runway cleanup. Part of the runway cleanup was ongoing during the final rolling of the crater. Runway cleanup consisted of an M151A2 jeep pulling a towed rotary broom sweeper in a circular pattern around the crater (Photo 14). The sweeping commenced at 2315 and finished at 2345.

Trafficking of test crater

57. Load cart. A load cart (Photos 15 and 16) was used to simulate the wheel load of an F-4 aircraft. The total weight over the F-4 wheel was 25,500 lb with a tire pressure equalling 286 psi.

58. Application of traffic. The load cart was positioned center of the large crater and passed 30 times across the crater. The passes were all in the same line. This was accomplished by stationing two ground guides (one in front and one in the rear of the truck), who directed the load cart back and forth across the crater.

59. Behavior of test crater. The test strip showed deflections ranging from 0.03 to 0.08 m. The largest deflections were on the low end of the crater cap and toward the edge. More than 50 percent of the test strip showed deflections exceeding 0.06 m.

Analysis of results and conclusions

60. Analysis of results. The technique used by the Air Force calls for a well-graded 1-1/2 in. minus crushed limestone, which meets Corps of Engineers specifications for base course material as specified in AFM 88-6, Chapter 2, Section 6, Table 1. Another requirement was that less than 10 percent of the material pass the No. 200 sieve. If crushed limestone is not available, then another locally suitable substitute conforming to the specifications for base course material can be used.

61. Since the Battalion has a limited budget, and combined with the fact that crushed limestone, besides being very expensive, is also extremely difficult to obtain in Germany, a substitute was used, namely a well-graded 0-32 mm aggregate locally available. The particular reference manual referring to specifications was not consulted to determine if the aggregate used met them. However, the Battalion has used this aggregate for many other exercises and obtained satisfactory results. One other point to remember is that crushed limestone will probably not be available in war, so we used what would be readily available.

62. A further point to consider is the moisture content of the aggregate. A recommended value is 2-5 percent by weight, but no more than 5 percent. The water content of the aggregate used was 6 percent. As can be seen in Table 2, at the time of the repair, an estimate of 5.5 percent was used to calculate the density. Only after the repair was completed did a laboratory analysis indicate 6 percent water content. However, this slight increase does not alter the results appreciably.

63. Conclusions. The conclusions that were reached after reviewing the results are:

a. Our results indicate that the repair was not satisfactory for the method employed. This is not to say that the method is poor; it's just that we had some different factors to consider, such as different aggregate and different aggregate moisture content.

b. The method is very simple and lends itself to troop use.

c. Tests should be done on material that is locally available on the German economy and would also be available in a time of crisis.

d. To properly evaluate this method with troops, the same materials must be used.

Photo 41

BN 25 Ready-Mix Concrete for Large Craters

Purpose

64. The purpose of this field test of project REREPS was to evaluate the repair of a large crater utilizing ready-mix concrete for the capping material. This is a permanent repair technique on which the Battalion has trained for 3 years. The repair technique has been documented in various after-action reports but not compared with an identical exercise. This section of the report shows a comparison between this exercise and an identical exercise conducted on 29 November 1979 (see paragraph 76). The comparison will show an average time of repair for various steps of the technique.

Methodology

65. The methodology employed has been developed over the past 3 years by members of this Battalion working in conjunction with the WES. The first step involves preparing the crater for select aggregate. This is accomplished by removing any unsuitable ejecta from the crater (by bulldozer) and pushing in suitable ejecta (less than 12 in.) from around the crater edges. The elevation of select debris should be 36 in. below the existing concrete surface prior to select aggregate being added. Select aggregate (0-32 mm) is then added in two lifts of 12 in. each. A value of 95 percent CE 55 is required for each lift. Once the select aggregate is to a level 12 in. below the existing concrete surface, the pedestal and headwall board are placed. Immediately thereafter, the screed and trail beams are positioned. Concrete is then added to the crater starting at the headwall board. Once a head is built up at the board, the screed beam is pulled in a circular motion around the crater maintaining a head in front of the screed beam at all times. As the screed beam is traversing the crater, personnel riding the trail beam begin to float the concrete. The screed and trail beams are then removed as is the headwall board prior to runway cleanup.

Test site - construction of crater

66. The Battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by

120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

67. The crater was constructed using a D7F crawler tractor to dig the crater. The crater was approximately 21.5 m in diameter and 2.2 m deep. Ejecta was "mounded" around the edges of the crater simulating a bomb explosion. Upheaved sections of concrete were strewn throughout the ejecta (Photo 2).

Concrete repair

68. Crater preparation. Crater preparation started as soon as a sweep to detect any unexploded ordnance was accomplished. The sweep was conducted by the advance party using mine detectors, both metallic and nonmetallic. At 0900, just 2 min after the platoon's main element arrived on site, a 5-yd scooploader began to push select small ejecta (no size larger than 0.3 m) into the crater (Photo 42). Shortly thereafter, a D7F dozer entered the crater to start spreading what the 5-yd scooploader pushed in. The D7F dozer also compacted the ejecta to some extent by traversing back and forth across the crater as it spread the ejecta (Photo 41). The 5-yd scooploader would also push all large, heaved sections of concrete and unsuitable ejecta to the side of the runway (Photo 5). These two vehicles worked as a team. They completed this task at 0952. The depth below the existing concrete runway surface as verified by a stringline check was now 0.9 m. A compaction test using a nuclear densimeter was conducted to determine degree of compaction effort applied to the ejecta by the D7F dozer. As shown in Table 3, a value of 87.3 percent CE 55 was achieved. (Note that the minimum required value was to be at least 85 percent.)

69. Backfill. As the crater preparation was being accomplished, select aggregate material (0-32 mm) was being stockpiled near the crater. (Figures 5 and 6 show the sieve analysis and grain-size distribution chart, respectively, of the select fill material.) Twenty-ton dump trucks hauled in the fill from a large stockpile approximately 10 km away. The first loads of fill arrived at 0905. A total of 500 metric tons were hauled in. Hauling was completed at 1100. Four 20-ton dump trucks were used to effect the haul.

70. As soon as the crater preparation was completed at 0952, the same 5-yd scooploader and D7F dozer began to push the stockpiled aggregate into the crater. Once sufficient aggregate had been pushed into the crater, the D7F dozer went back into the crater to start spreading the aggregate. The 5-yd scooploader remained pushing the stockpile into the crater until sufficient aggregate had been pushed in to fill the first 12-in. lift. The D7F dozer continued to spread aggregate until 1015. At 1017, the 30-ton vibratory roller entered the crater and moved back and forth across the crater until 1045 (Photo 6). Again, density checks were taken (Photo 31) showing that an average value of 96.6 percent CE 55 was obtained (Table 1). (Note that the minimum required value was 95 percent.) The second lift was again accomplished in the same manner with two exceptions. The 20-ton dump trucks now back-dumped directly into the crater (Photo 8), and a grader was used to level the aggregate. The 30-ton vibratory roller again entered the crater and compacted until 1130. Three separate density checks were made at intervals during the compacting process to ensure at least 95 percent CE 55 was obtained (Table 1 for results).

71. Setting pedestal and headwall board. At 1131, a 25-ton P&H crane set the pedestal in place (Photos 43, 44, and 45). It was placed approximately in the center of the crater. The pedestal can be hand carried into place by six persons to speed up the process or if a crane is not available. The pedestal was leveled, and then a round, circular steel bar was placed through the center hole of the pedestal. This bar was used to attach the screed and trail beams to the pedestal. When the pedestal was finally leveled, a headwall board was placed between the pedestal and the outside edge of the crater (Photo 46). The function of this board was to form a wall for the concrete to butt up against so that a head can be created in front of the screed beam. U-share pickets were driven flush to the top of the board to hold it in place.

72. Hooking up screed and trail beams. Concurrent with setting the concrete pedestal, other operations were in progress. A rotary sweeper pulled by a jeep was cleaning the area around the crater (Photo 47) while a 250-cfm Davey air compressor was being used to clean the inside

edge of the crater with compressed air (Photo 48). As the cleaning around the crater was taking place, the screed and trail beams were being off-loaded from the 25-ton low-bed trailer by the crane (Photo 49). Once the cleaning was complete, the screed beam was set in position by the crane as was the trail beam (Photo 50). The screed beam is a box beam that screeds the concrete flush as it is dragged around the crater. The screed beam is pulled around the crater by a 2-1/2-yd loader (Photo 51). The trail beam is a box girder beam with a wooden platform mounted on top for personnel to lie on while finishing the concrete surface. Both beams were in place by 1220. (Photos 52 and 53 show in detail how the beams are connected to the pedestal.)

73. Placing concrete. Concrete placement began at 1223. The first truck placed its load directly against the headwall board so that a head could be developed. When enough concrete was placed to build up a head before the screed beam, the screed beam was pulled forward to strike off the concrete flush with the old, existing concrete. This process continued around the crater until all concrete was placed. The last truck of concrete was placed at 1403. (Photos 54 through 65 show views of the technique in process.)

74. Finishing concrete. As previously mentioned, the trail beam is utilized to provide a working platform over the concrete for personnel finishing the concrete surface (Photos 66 and 67). The trail beam in this exercise followed the screed beam by approximately 10-12 ft. As noted in Photo 68, the trail beam is moved by hand because it has wheels that rest on the existing pavement surface. Personnel utilized wooden floats to finish the surface. The edges were also worked with floats to ensure a good bond between the new and existing concrete surfaces. Once the entire surface had been floated, the screed and trail beams were removed by the crane.

75. Runway cleanup. Runway cleanup consisted of several phases. Early in the repair process, a Cat 120 road grader cleaned the large debris from the runway surface. Before placing the concrete, a towed rotary sweeper was used to clean around the crater. Finally, the towed rotary sweeper was again used to make a final sweeping of the runway surface (Photo 14).

Comparison with large crater
repair conducted on 29 November 1979

76. A similar concrete exercise was performed by B Company, 293rd Engineer Battalion, on 29 November 1979. The following chart depicts the differences in times for various activities between the two exercises.

	A CO Exercise 2 Nov 79, min	B CO Exercise 29 Nov 79, min
1. Crater Prep*	52	50
2. Backfill**	96	127
3. Concrete Cap†	150	125
	Total = 298	Total = 312

A study of the chart reveals little difference in the overall time to complete the entire crater repair. However, differences in other times can be explained as follows. B Company used a K300 (Koehring Model) Motorized Sheepsfoot Roller to achieve compaction on the aggregate lifts, while A Company used a 30-ton vibratory roller. The sheepsfoot roller made many more passes in attempting to achieve the required density than did the 30-ton vibratory roller. (In fact, the compaction results obtained did not meet the minimum required values (Table 4). As shown in the table, the water content was 8.25 percent, much more than the 6 percent that A Company had. This had a definite effect on the compaction results.) Also, B Company spent more time defining the crater edge than A Company. The difference in concrete placement times can best be explained by A Company placing 99 cu m, while B Company only placed 75 cu m. It should be noted here that both units had to wait on concrete delivery by the ready-mix trucks after the first few trucks had placed their loads. It is estimated that 30 min or more were spent

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* Crater Prep involves clearing debris from around the crater, clearing unusable ejecta from the crater, pushing usable ejecta (less than 12 in. in size) into the crater, and compacting with a dozer to 85 percent CE 55.

** Backfill consists of placing and compacting two 12-in. lifts, and compacting each lift to 95 percent CE 55.

† Concrete Cap involves placing and leveling the pedestal, placing and securing the headwall board, cleaning the concrete edge surfaces, placing the screed and trail beams, placing, screeding, and finishing the concrete, and finally removing the beams.

waiting on concrete ready-mix trucks. Other than for the differences discussed, the same procedures were followed during both exercises. An analysis of B Company's compaction results can be found in Table 4.

Analysis of results and conclusions

77. Analysis of results. Concrete cylinders were taken during both exercises for compression tests. They were site cured, that is, left on site until it was time to take them to the lab and be tested. No special method of curing was employed, in fact, they were just set on the ground off the runway surface and tagged. As shown by the results of the compression tests, the ultimate compressive strength of the concrete was not very high. The reason can be largely attributed to the curing process to which the cylinders were exposed. However, these were the same conditions to which the concrete in the cap was exposed. During the month of December, the weather was very cold, staying mostly in the 30's. Most of November was in the 40's and occasionally in the 50's. The test results for the 2 November exercise (Figures 13, 14, and 15) were better than for the 29 November exercise (Figures 16, 17, and 18).

78. The load cart (Photos 15 and 16) was passed over the concrete cap 30 times in the same lane for the cap placed on 2 November 1979. There were no deflections or cracks observed. The test was conducted 7 days after the cap had been placed. There was no test conducted on the cap placed on 29 November 1979 because of an inoperable load cart.

79. Conclusions. The conclusions that can be drawn from the two exercises are:

- a. To effect this repair simultaneously on multiple large craters would require a stockpile of items on hand including pedestals, screed beams, trail beams, a source of select aggregate, and a local national source of concrete supply.
- b. Since this is a permanent repair, the 4-hr time rule should not apply. Rather, the quality of the work should govern.
- c. Continue using the vibratory roller to achieve better and faster compaction results.

d. The repair time is dependent on the expeditious delivery of concrete.

e. During very cold and very hot weather, the concrete must be cured properly. No attempt was made to cure the concrete, as we are more often concerned with the technique involved and less with the compressive strength of the finished product.

Table 3

RAREPS Density Tests (2 November 1979)

Test No.	% w	γ_d	% Compaction
1	5.5	111.54	87.3
2	5.5	117.36	91.9
3	5.5	124.98	97.9
4	5.5	121.28	94.9
5	5.5	118.98	93.2
6	5.5	119.65	93.7
7	5.5	124.39	97.4

Reading Time/Test - 1 or 2 min Testing Depth - 6 in.

Remarks

Test 1 was conducted on the lowest layer of fill, which was compacted only with dozer. Required compaction value for this layer was 85 percent. Required compaction value for all other layers was 95 percent.

Tests 2, 3, and 4 were conducted on a lower, roller, compacted layer. Test 3 was a retest of test 2 after further compaction. Average compaction value for this layer was 96.6 percent.

Tests 5, 6, and 7 were conducted on an upper, roller, compacted layer. Compaction of this layer was not final until test 7 was made.

Test 1 was taken toward the center of the crater, while all other tests were taken toward the edge. Water content was estimated at 5.5 percent. Maximum dry unit weight was 127.70 pcf.

Soils Technician
SP4 Michael Iezzoni

Table 4

RERPS Density Tests (29 November 1979)

Test No.	% w	γ_d	% Compaction
1	8.25	106.95	83.7
2	8.25	118.03	92.4
3	8.25	114.25	89.5
4	8.25	122.91	96.2
5	8.25	114.71	89.8
6	8.25	118.84	93.0
7	8.25	117.20	91.8
8	8.25	122.61	96.0

Reading Time/Test - 1 or 2 min Testing Depth - 6 in.

Remarks

Material tested was 0-32 mm gravel.

Tests 1 and 2 were done on the bottom lift in the crater. Minimum required compaction value was 85 percent. Average compaction value was 88.05 percent.

Tests 3 and 4 were done on the second lift. Minimum required compaction value was 95 percent. Average compaction value was 92.8 percent.

Tests 5 through 8 were done on the top lift. Minimum required compaction value was 95 percent. Average compaction value was 92.6 percent.

Soils Technician
SP4 Michael Iezzoni

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Samples taken 2 November 1979 Concrete Strength Test Report

TO	FROM	DATE	CMT 1
S-3 293rd Engr Bn APO 09034	Materials Testing Sec 293rd Engr Bn APO 09034		

Following are the results of test requested in CMY 1.

Type Test: Compressive

Date and time of test: 9 November 1979, 1615

The samples were cured: On Site

The samples were capped with: Sulfur Compound on 9 November 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	7-Day Compressive Strength, psi
1	6	15,000	530.52
2	6	14,000	495.15
			Average 512.84

Note: Concrete slump was 3.5 in.

* For Compressive Strength Test, dimension is cylinder diameter.

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 13

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Samples taken 2 November 1979 Concrete Strength Test Report

TO	FROM	DATE	CMT 1
S-3 293rd Engr Bn APO 09034	Materials Testing Sec 293rd Engr Bn APO 09034		

Following are the results of test requested in CMY 1.

Type Test: Compressive

Date and time of test: 16 November 1979, 1245

The samples were cured: On Site

The samples were capped with: Sulfur Compound on 16 November 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	14-Day Compressive Strength, psi
1	6	29,000	1,025.66
2	6	30,000	1,061.03
			Average 1,043.35

Note: Concrete slump was 3.5 in.

* For Compressive Strength Test, dimension is cylinder diameter.

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 14

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Samples taken 2 November 1979 Concrete Strength Test Report

TO	FROM	DATE	CMT 1
S-3 293rd Engr Bn APO 09034	Materials Testing Sec 293rd Engr Bn APO 09034		

Following are the results of test requested in CMY 1.

Type Test: Compressive

Date and time of test: 30 November 1979, 1345

The samples were cured: On Site

The samples were capped with: Sulfur Compound on 30 November 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	28-Day Compressive Strength, psi
1	6	44,500	1,573.86
2	6	46,000	1,626.92
			Average 1,600.38

Note: Concrete slump was 3.5 in.

* For Compressive Strength Test, dimension is cylinder diameter.

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 15

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Sample taken 29 November 1979 Concrete Strength Test Report

TO	FROM	DATE	CMT 1
S-3 293rd Engr Bn APO 09034	Materials Testing Sec 293rd Engr Bn APO 09034		

Following are the results of test requested in CMY 1.

Type Test: Compressive

Date and time of test: 6 December 1979, 1539

The samples were cured: On Site beginning 29 November 1979

The samples were capped with: Sulfur Compound on 3 December 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	7-Day Compressive Strength, psi
1	6	12,500	442.11

* For Compressive Strength Test, diameter is cylinder diameter.

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 16

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Sample taken 29 November 1979 Concrete Strength Test Report

TO	FROM	DATE	CMT 1
S-3 293rd Engr Bn APO 09034	Materials Testing Sec 293rd Engr Bn APO 09034		

Following are the results of test requested in CMY 1.

Type Test: Compressive

Date and time of test: 13 December 1979, 1445

The samples were cured: On Site beginning 29 November 1979

The samples were capped with: Sulfur Compound on 13 December 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	14-Day Compressive Strength, psi
1	6	15,000	530.52

* For Compressive Strength Test, diameter is cylinder diameter.

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 17

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
AEUEG-XOP	Samples taken 29 November 1979 Concrete Strength Test Report

TO	FROM	DATE	CMT 1
S-3 293rd Engr Bn APO 09034	Materials Testing Sec 293rd Engr Bn APO 09034		

Following are the results of test requested in CMT 1.

Type Test: Compressive

Date and time of test: 27 December 1979, 1530

The samples were cured: On Site beginning 29 November 1979

The samples were capped with: Sulfur Compound on 24 December 1979

Sample	Dimension* ± 0.01 in.	Max Load, lb	28-Day Compressive Strength, psi
1	6	25,000	884.19
2	6	27,500	972.61
			Average 928.40

* For Compressive Strength Test, diameter is cylinder diameter.

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

Figure 18

Photo 42

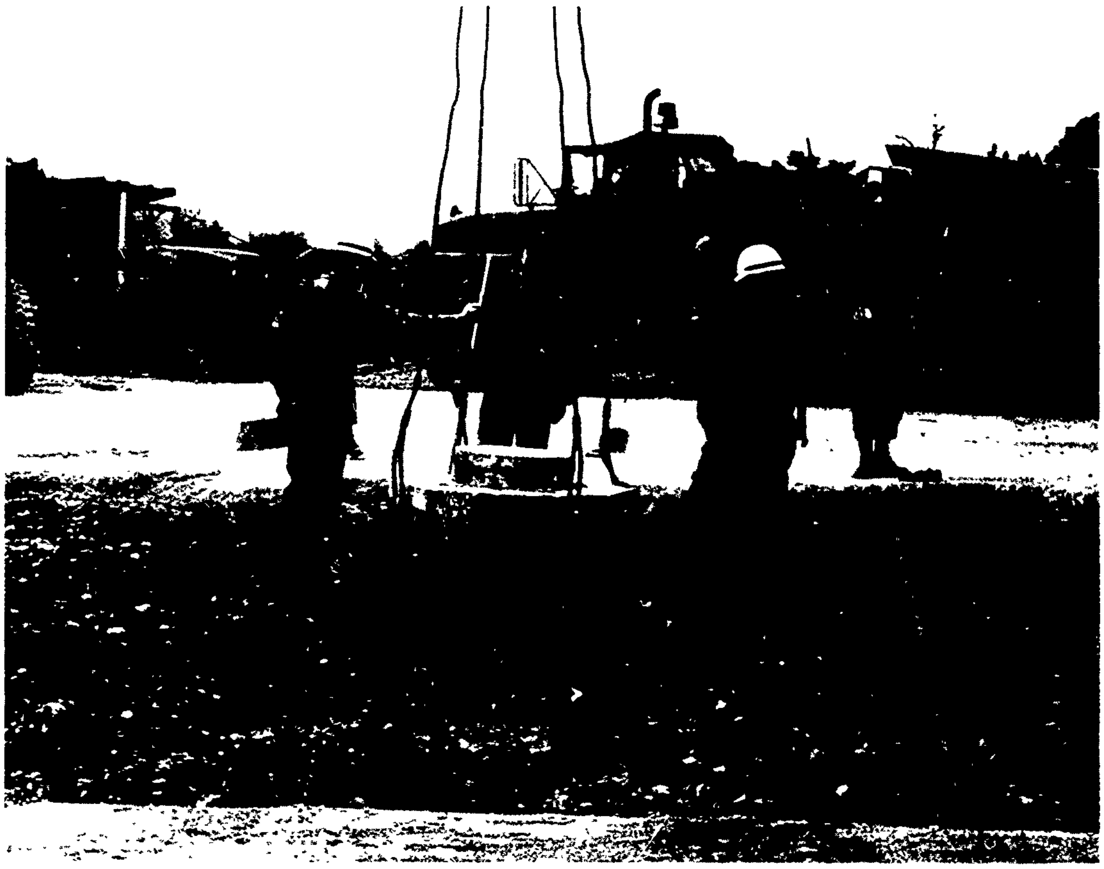


Photo 43

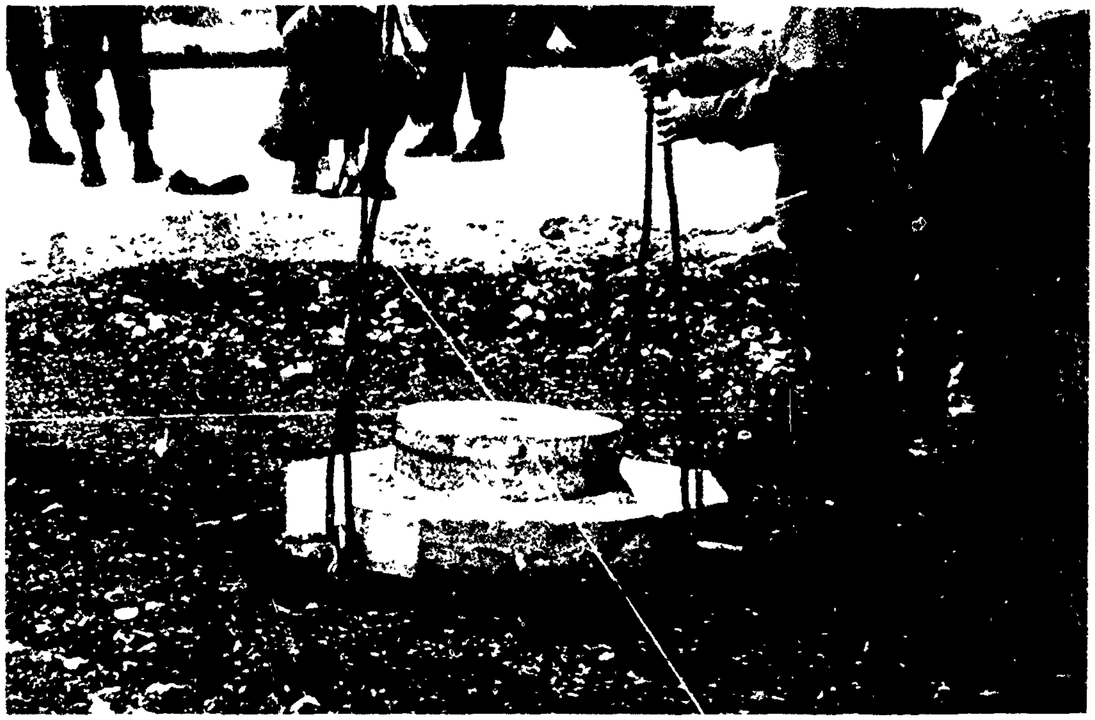


Photo 44

Photo 45

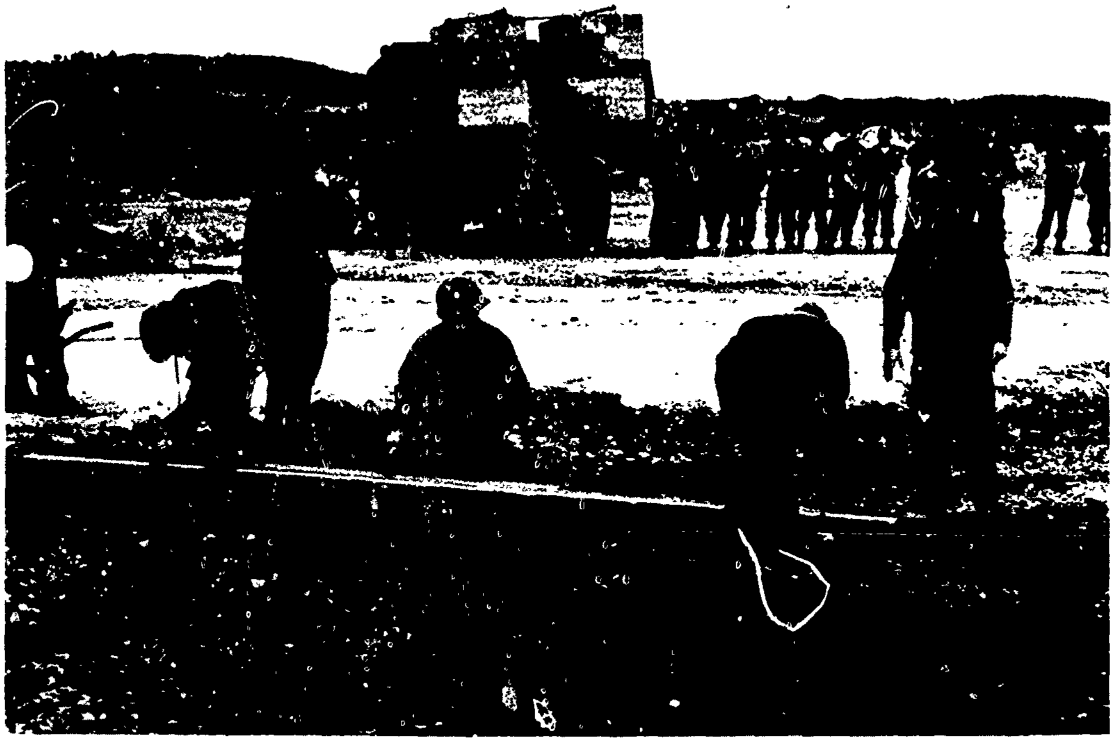


Photo 46

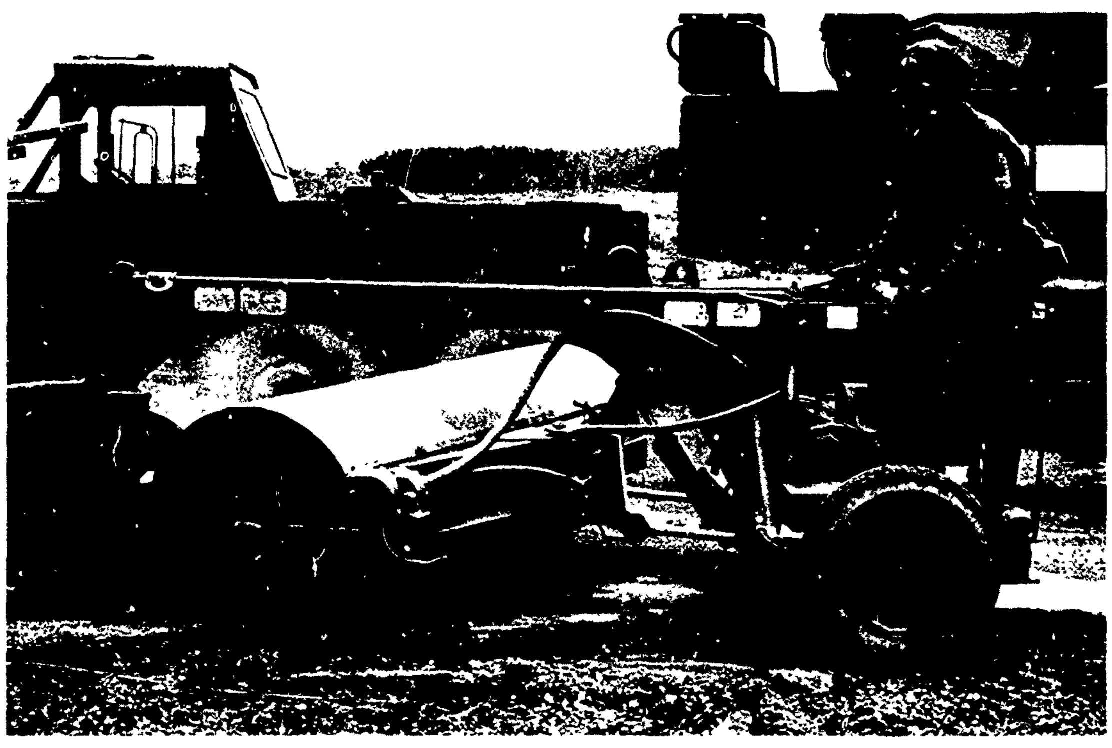


Photo 47

Photo 48

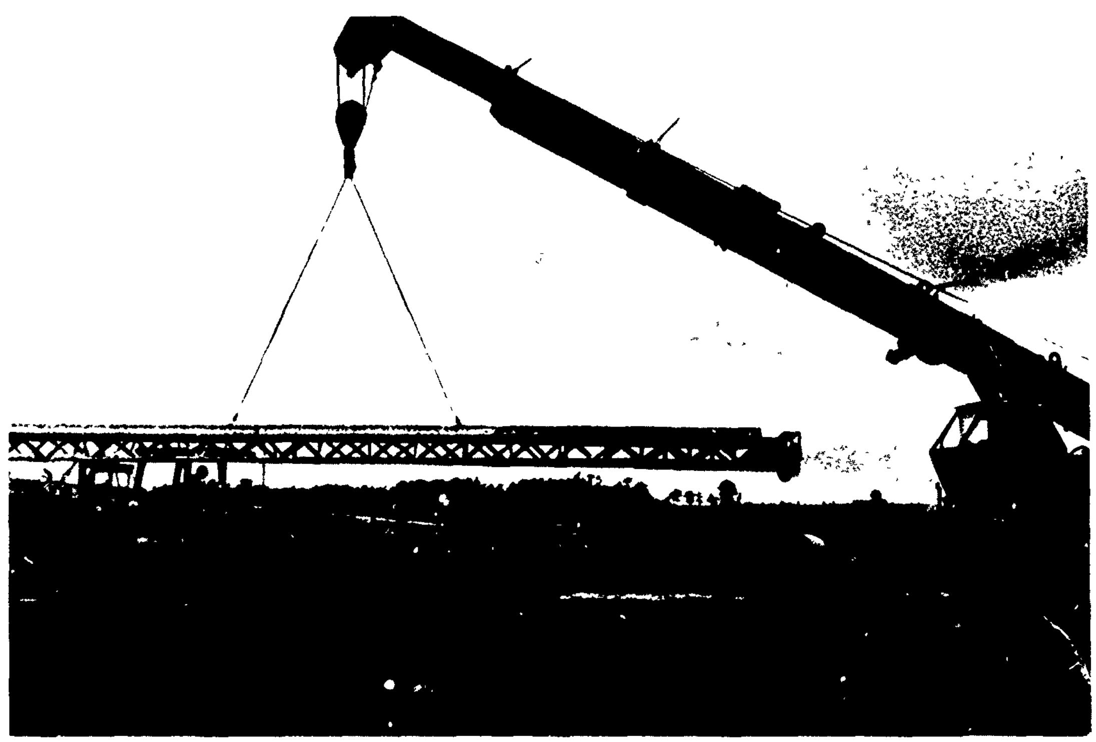


Photo 49

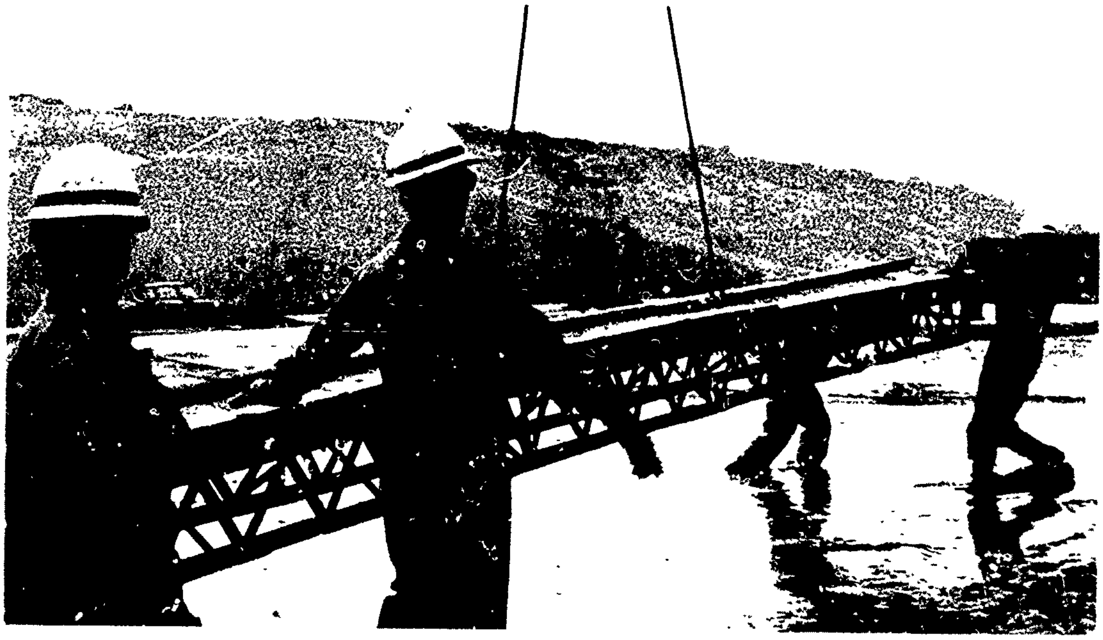


Photo 50

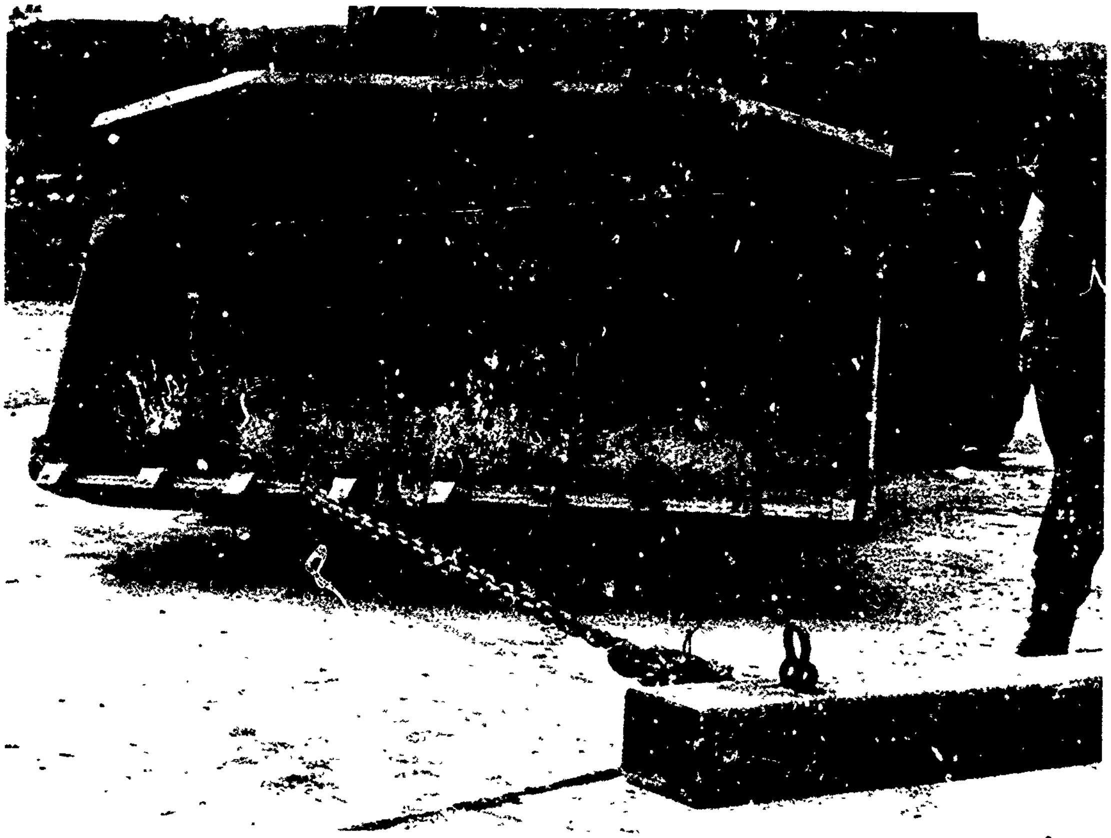


Photo 51

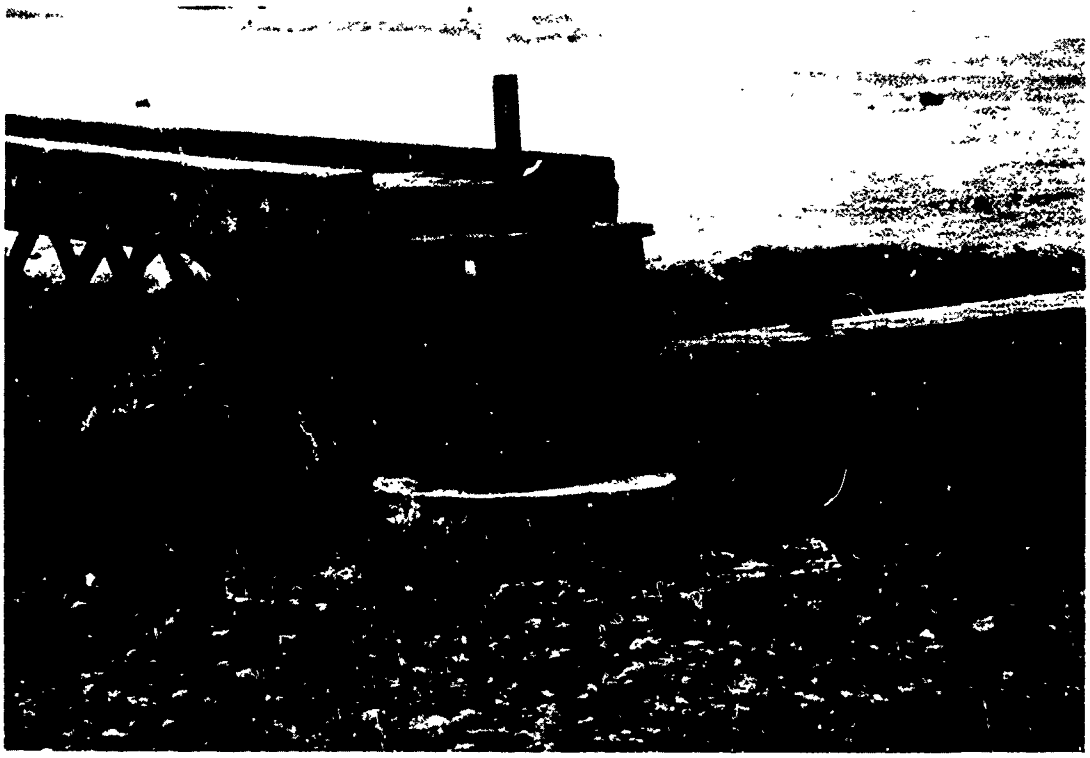


Photo 52

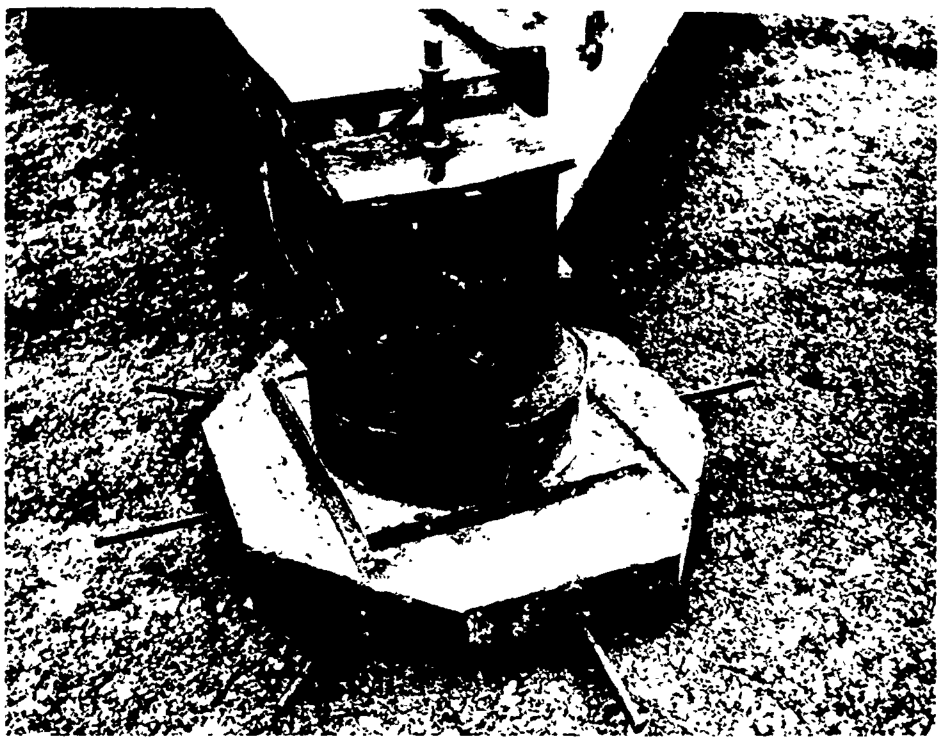


Photo 53

Photo 54

Photo 55

Photo 56

Photo 57

Photo 58

Photo 59

Photo 60

Photo 61

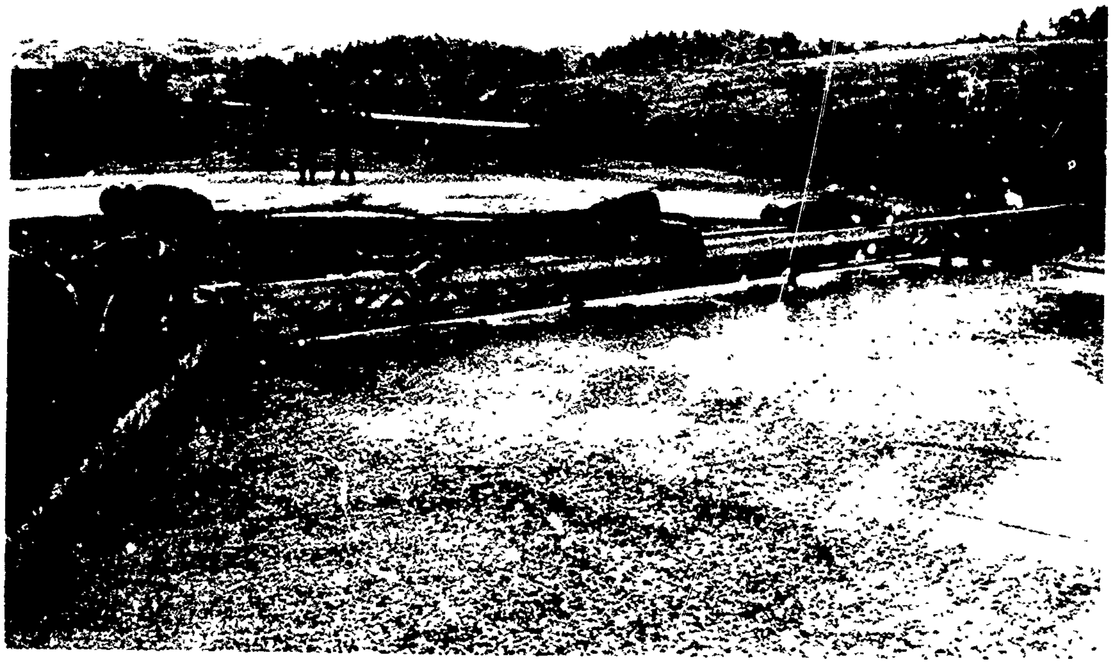


Photo 62

Photo 63

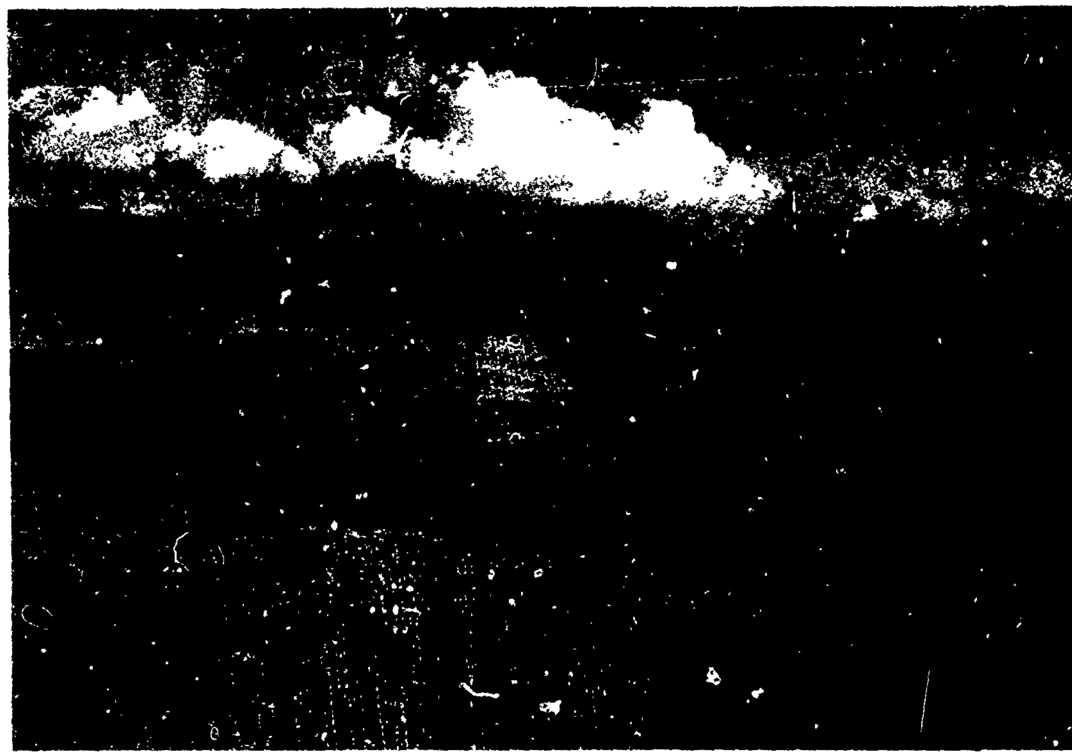


Photo 64

Photo 65

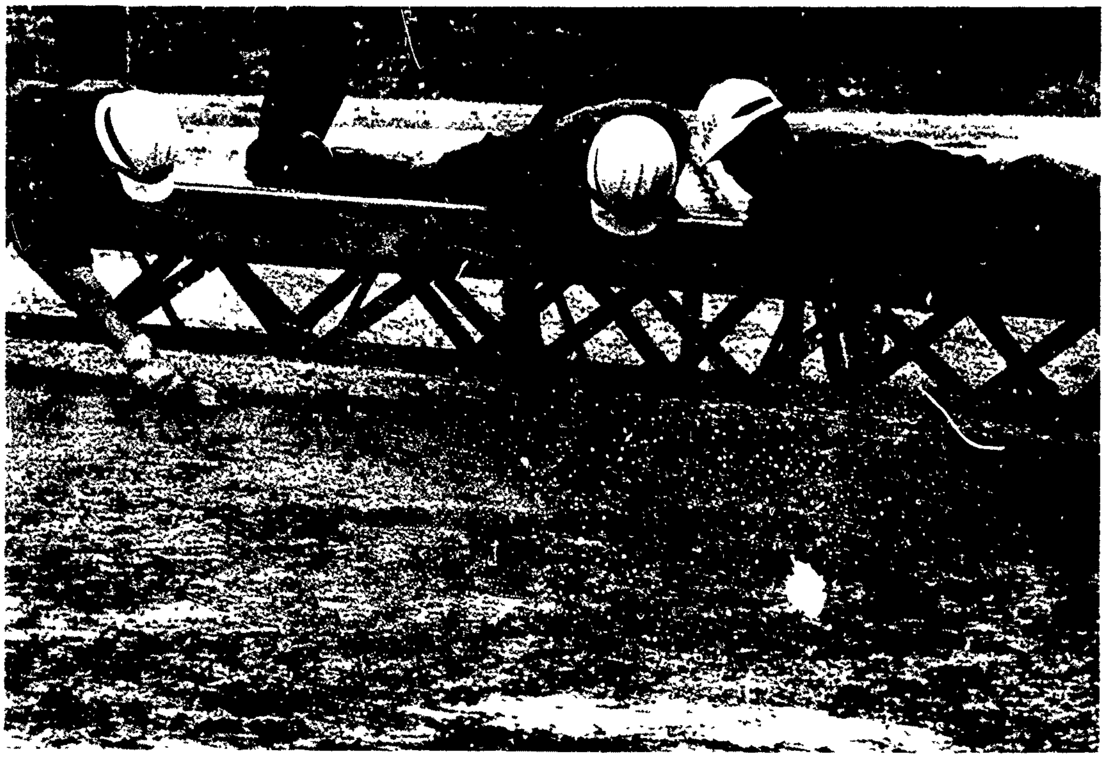


Photo 66

Photo 67

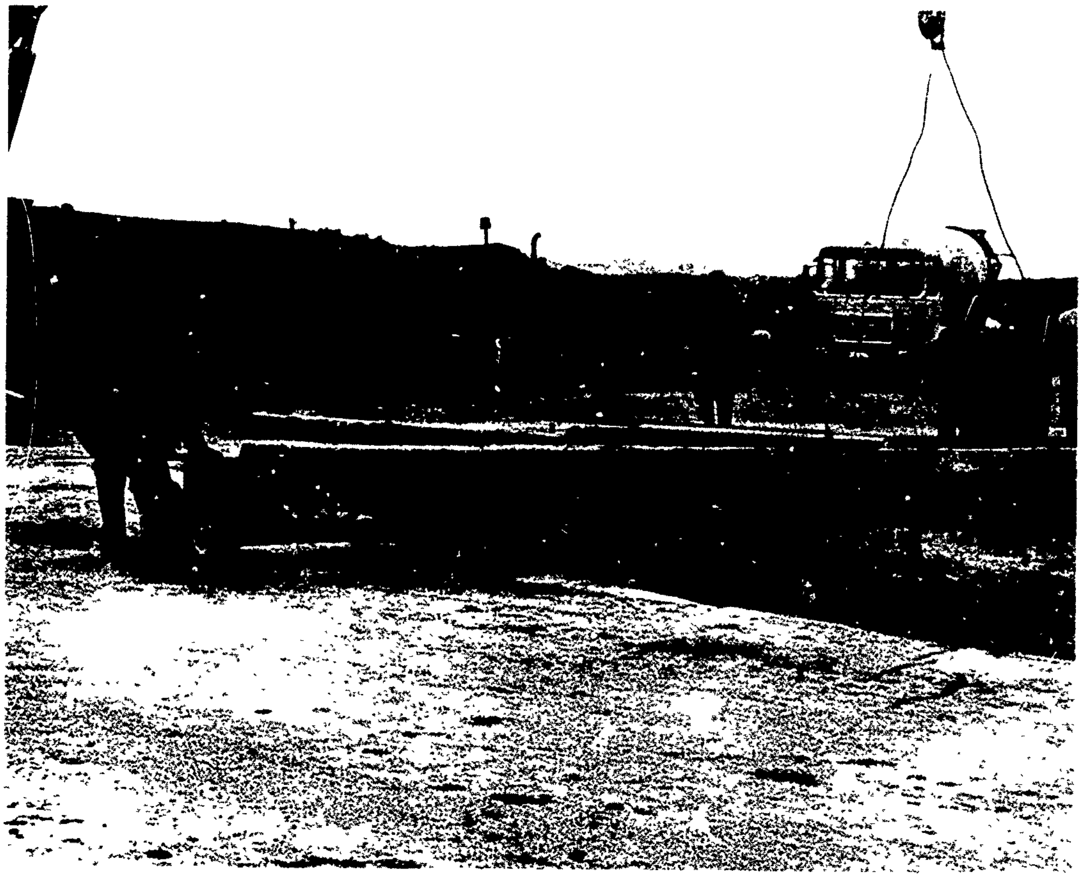


Photo 68

Spall Repair Using Silikal^R-R7/Bw Plastic Mortar

Purpose

80. The purpose of this field test of project REREPS was to evaluate the repair of spalls using Silikal^R-R7/Bw Plastic Mortar to determine:

- a. Time of repair per spall.
- b. Ease of repair and suitability for use by troops.
- c. Materials required.
- d. Safety precautions required.
- e. Performance characteristics.

Background

81. Silikal^R-R7/Bw Plastic Mortar is a registered trademark product of the Karl Ullrich Company KG of Mainhausen, Federal Republic of Germany. This particular product was developed for the Ministry of Defence of the Federal Republic of Germany during a research and development program conducted in 1974 and 1975. The purpose of this program was to develop a material, capable of meeting very rigid performance criteria, for use in the rapid repair of airfield surfaces. One of the major performance criteria was the attainment of full load bearing capacity within 2 hr. The German Army and Air Force repair crews use this product to repair small holes in the runway surface according to the methodology outlined below.

Methodology

82. The sequence of events in the repair of a spall is as follows:

- a. Damaged areas of concrete are to be cleaned of all loose parts, dust, and contamination with the aid of hammers, grinding tools, and brooms. If the surface is wet, it must be dried, e.g. with a propane flame.
- b. Mixing the plastic mortar is the next step. This is best carried out by two men. Man No. 1 opens the paper bag and removes the polyethylene blending bag and the white paper bag with the necessary catalyst. Man No. 2 pours the powder mixture into the polyethylene bag that is held open by man No. 1. He then opens the white bag and pours the catalyst over the powder mixture. Subsequently, he opens the hardener can - at temperatures above 0°C at the top and at subzero temperature at the bottom. In the latter case, it is important that

the aluminum container is penetrated. The same man pours the hardener liquid into the blending bag. Man No. 1 now closes the bag by twisting the open end leaving a small open space above the surface of the mortar. Holding the bag closed with one hand, he grasps the bag at the bottom and kneads, rolls, and shakes the content for 1-2 min.

c. The next step is to place the mortar into the spall. At the repair site, the bag containing the mixed plastic mortar is slit, e.g. with a trowel. The mortar is poured out and smoothed down with a steel trowel. The working life of the mortar is only 10-15 min, so work must be done rapidly. The curing time, the time until full load bearing capacity is reached, is 60-90 min. Coarse filler, up to 20 percent of the total mixture, can be blended into the mortar to stretch its use. Coarse filler is anything over 3 mm, but not larger than 30 mm.

d. The final step is to clean the tools after use. The easiest way is to pour some hardener liquid into a polyethylene bucket and put in the tools. Then, by using a normal paint brush, the mortar can be brushed off before it cures. Alternate cleaning liquids are acetone, metylenchloride, or trichloethylene.

83. One final point that should be noted concerns the safety requirements. When working with this material, workmen should wear gloves, boots, and a protective facial mask. Even though it is nontoxic, inhalation of large amounts of the vapors can be hazardous. One other point to remember is that the liquid hardener is easily inflammable. Consequently, no smoking was allowed.

Test site - construction of spalls

84. The Battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

85. The spalls were created by drilling holes in the concrete slab using a Davey 250-cfm air compressor and pavement drills. The spalls were approximately 0.15 m deep and 0.4 m in diameter (Photo 38).

Spall repair

86. Spall preparation. The first step, accomplished by the spall repair team, was to prepare the spall to accept the Silikal^{R}. This step commenced at 0915. All loose pieces of concrete were swept away from

the spall. One man accomplished this with a broom. The spall was then blown clean using compressed air from a Davey 250-cfm air compressor (Photo 69). Finally, the inside surfaces of the spall were dried using a torch (Photos 70 and 71).

87. Preparing and mixing Silikal^R. Prior to actually mixing the Silikal^R, several safety precautions were observed. The two men that were to mix the Silikal^R put on protective masks (M17/M17A1) with hoods, gloves, and rubber overshoes (Photo 72). They then proceeded with the steps as outlined previously in paragraph 82 and shown in Photos 73, 74, and 75. The addition to the procedure was the addition of a filler gravel to the mortar mix while still in the blending bag. The reason for the addition of this filler was to stretch the mortar. Approximately two shovelfuls were added per bag (Photo 76).

88. Addition of Silikal^R to spall and surfacing. After the filler gravel had been thoroughly mixed in with the mortar mix, the bag was held over the spall by one man while another man slit the bottom of the bag with a steel trowel. The mortar flowed out of the bag into the spall (Photo 77). One bag was sufficient to repair one spall. The mortar mix was then draped flush with the existing concrete surface with a steel trowel (Photo 78). This step completed the spall repair. The time was 0930. The only thing left to do was let the Silikal^R cure. One hour later, the spall was checked. It was extremely hard; in fact, it could be stepped on without any penetration. The one thing noticed was a difference in elevation between the repaired area and the existing concrete surface. The repaired area was approximately 1 cm lower.

Analysis of results, conclusions, and recommendations

89. Analysis of results. The results we obtained were very satisfactory. The total repair time per spall was 75 min using two men (includes cure time of 60 min). Multiple spalls could be repaired utilizing a team approach. Crews for surfacing, mixing, and preparation would be employed. Obviously, the mixing and surfacing crews would of necessity be the largest.

90. We found that the method does not really require the wearing of the protective mask. However, we also believe that we will be working in a nuclear, biological, and chemical environment on the air bases anyway following an attack, so it would be logical that the repair would be carried out under those conditions. There was no degradation of efficiency in performing the repair with masks and gloves on. It is a very simple procedure and well suited to troop use.

91. There are also not many support pieces of equipment or materials required. A 5-cfm portable air compressor could have been used to blow any loose concrete chips from the spall instead of a 250 cfm. In fact, even if this is not available, a broom will get most of the debris out. The only other material needed is several steel trowels and an oil can opener.

92. The difference in elevation between the repaired area and the surrounding concrete that was experienced is not really critical. During the curing process, the mix must have settled somewhat and at the same time shrunk due to the loss of surface moisture. The initial repair is the critical factor, and a change of 1 cm in the elevation of the runway surface should not affect the ability of an aircraft to land or takeoff. To offset this shrinkage effect, the mortar can be mounded slightly and then worked down just prior to setting. We also found that the Silikal^{R} bonded to the old concrete extremely well.

93. Conclusions. The conclusions that can be reached following this exercise are:

a. The method using Silikal^{R} with troops is acceptable and easy.

b. Silikal^{R} meets all performance characteristics (quick cure, strength, and rapid emplacement procedure).

c. This product could potentially be used for larger scale operations if a suitable mixing container, i.e. concrete mix mobile-type vehicle, could be used to batch larger amounts at once.

d. If larger batches can be made, then a suitably fast method to place and screed the product must be developed, possibly using a vibratory screed beam attached via a special hookup to an existing vehicle.

e. Very few materials are needed (brooms, trowels, hammer, shovel, can opener, and a straightedge).

94. Recommendations. During subsequent testing, it would be beneficial to try this repair material on a small crater (6 m in diameter) to see if a method of employment can be devised. It would require the capability to batch large amounts of Silikal^R at one time and, therefore, an equally fast method of placing and finishing. The only consideration that might limit the scale of the test would be the cost. To perform the repair of a 6-m crater with a 2-in. cap would cost approximately \$6500 for the Silikal^R alone.

Supplemental data provided
by the Karl Ullrich Company

DESCRIPTION AND INSTRUCTIONS

for the application of Silikal - R7/Bw plastic mortar

1. Areas of Use/Application

1.1. Normal concrete-repair (as part of normal maintenance- and repair-work)

1.2. Repair of small-size damages to runways.

2. Safety Regulations

Whilst using resin and hardener, local safety standards for chemicals have to be observed. Comparable German regulations are published in "Verordnung uber gefährliche Arbeitsstoffe", issue May 1, 1976.

2.1. Most important rules:

Rubber boots, acid-prove protective gloves, protective facial masks, water spray bottles for eyes

2.2. No smoking, no eating at jobside

3. Description

Silikal-R7/Bw is a plastic mortar on methacrylic basis. The resin component is a powder and the hardener a liquid.

Whilst blending resin and hardener in proportion 7.5:1 in a polyethylene-bag a pourable mortar is produced.

The method is called the "powder-liquid method", comparable with methods used to produce cement-bound mortars.

Silikal R7/Bw is usually applied without additional fillers (the powder already contains about 80% special quartz-sand sized 0-1.5 mm as filler). It is possible to add additional stone material or small concrete parts (up to 15 to 20% of the total mixture) after blending the mortar. Furthermore it is possible to add graded fillers to about 50% of the mortar which however makes the blending job more difficult. Blending instructions are laid down in tables 1 and 2 of enclosure No. 1.

The plastic mortar Silikal R7/Bw can be applied at temperatures in the range of

$$\underline{-20^{\circ}\text{C and } +40^{\circ}\text{C}}$$

4. Packaging Units

One packaging unit of Silikal R7/Bw consists of:

1 bag powder mixture, 15 kg
1 tin can hardener liquid, 2 liters

4.1. Bag with 15-kg powder mixture

The bag is a four-layer paper bag with a waterproof polyethylene liner. In the bag on top of the powder are enclosed:

4.1.1. A white paper bag containing 235 g of powdered catalyst (benzoylperoxide)

4.1.2. A Polyethylene-blending bag, size 640 x 670 mm, 0.1 mm thick, with welded bottom.

4.2. The tin can contains a 20-mm aluminum enclosure at the bottom. Top and bottom are gold-lacquer coated. The mantle is white with a blue stripe marked with silver ice crystals around the bottom (dimensions: 130-mm diameter, 175 mm high). The tin cans are packed in paper cartons containing 6 cans.

5. Storage Stability (Shelf Life)

The manufacturer guarantees, if the storage temperature never exceeded 25°C, the following shelf life for the components:

5.1. Silikal - R7/Bw powder. . . . . practically no limit

5.2. Benzoylperoxide powder. . . . . at least 5 years

5.3. Silikal R7/Bw hardener liquid and accelerator for curing at subzero temperature (down to -20°C) . . . . . at least 8 years

6. Consumption of Material (see table 1 and 2 of encl. 1)

Consumption for treating a plate of 1 sqm and 10 cm thickness (defined as biggest "small damage" for rapid runway repairs - Startbahnschnellinstandsetzung):

$$228 \text{ kg} = \frac{228 \text{ kg}}{17 \text{ kg}} \text{ (unit weight)} = \text{13, 4 packaging units (if no extra filler is added)}$$

The required amount of Silikal R7/Bw can be cut in half, if extra filler is added.

7. Tools and Apparatus Needed

Polyethylene bucket (10 l), paint brush, broom, steel trowels, straightedge, shovel, sledge, oil-can opener, protective clothing (see section 2.1 - important rules).

8. Job Routing

8.1. Pretreatment of damaged areas

There is a basic difference between two kinds of application:

8.1.1. Concrete repair jobs such as broken edges, eroded surfaces, filling of cracks, etc.

Applied method:
Damaged areas are to be cleaned of all loose parts, dust and contamination with the aid of hammer, grinding tools, brooms, etc. If the surface is wet, it must be dried, e.g. with a propane flame.

8.1.2. Repair of larger holes, e.g. from bomb fragments, which have completely penetrated the concrete.

Applied method:
What has been thrown clear of the crater should be shoveled back and compacted up to the lower edge of the concrete (using manual or power shovels).

9. Cleanup of Tools

The hardener liquid is poured into a polyethylene bucket and the tools are cleaned periodically using a normal paint brush before the mortar is set (cured).

This contaminated liquid can be reused for mixing fresh mortar during the same day. Contaminated liquid, however, should never be poured back into the original tin can or used for blending mortar the next day, even if the hardener is still liquid.

Alternate solvents, which can be used for cleanup are acetone, metylenchloride, or thrichlorethylene (these, however, should never be mixed into the mortar).

10. Pertinent Information

10.1 Silikal - R7/Bw hardener liquid

Inflammability:	easily inflammable flash point 10°C Safety classification for road transport: 111 a 1 a
Toxicity:	not toxic However, hazardous on inhalation of vapours (MAK-figure: 100 ppm - ppm = 410 mg per cubic meter), swallowing or in contact with skin.

10.2 Benzoylperoxide 50% (= powdered catalyst which is added to powder mixture in small amounts from white paper bag).

In this case, a 50% phlegmatized type is used. Safety class VII (organic peroxides) for road transport.

Furthermore, the manufacturer

Karl Ullrich & Co. KG
Ostring 23
D - 6451 Mainhausen
Tel.: 061 82/32 36, telex 41 84 557 sili d

refers to the German Safety Rule "Verordnung über gefährliche Arbeitsstoffe" issue Mai 1, 1976, to be applied.

Enclosure 1
to Description and Instructions for the Application of Silikal R7/Bw of the Karl Ullrich & Co. KG

	without added sand		with added sand					
			2 - 8 mm		2 - 16 mm		2 - 32 mm	
components	kg	% weight	kg	% weight	kg	% weight	kg	% weight
powder components (powder and peroxide)	15.00	89.02	15.00	60.36	15.00	47.10	15.00	41.61
hardener liquid	1.85	10.98	1.85	7.44	1.85	5.81	1.85	5.14
sand 2-8 mm	--	--	8.00	32.20	3.00	9.42	4.80	13.31
sand 8-16 mm	--	--	--	--	12.00	37.67	6.40	17.75
sand 16-32 mm	--	--	--	--	--	--	8.00	22.19
	16.85	100.00	24.85	100.00	31.85	100.00	36.05	100.00

Table 1: Blending Instructions (according to manufacturer)

Composition (see instruction Table 1)	Silikal-R7/Bw (kg)	added filler (kg)	number of packaging units
Silikal-R7/Bw	228.00	--	13.4
Silikal-R7/Bw + Sand 2 - 8 mm	154.58	73.42	9.1
Silikal-R7/Bw + Sand 2 - 16 mm	120.61	107.39	7.1
Silikal-R7/Bw + Sand 2 - 32 mm	106.57	121.43	6.3

Table 2: Required Quantity for a 1 sqm x 10 cm thick area

PROPERTIES OF THE ACRYLICS

1. MMA-resins (MMA = methylmethacrylate) can be formulated with very low viscosities providing optimal penetration of the substrate in primers, sealants and injection resins.

2. The increase in viscosity at lower temperatures is hardly noticeable - which is very important, as the same mixing and same application methods can be used at all temperatures. An added advantage is that MMA-resins inherently are non-sticky.

3. As opposed to 2-compartment resins curing through polyaddition, such as polyurethanes and epoxies, where the reactive components have to be dosated exactly, MMA-resins cure through polymerization, which is started through the addition of a special starter, the amount of which may be varied within rather wide boundaries, which guarantees a higher level of safety in use.

4. MMA-resins cure without reduction in physical or chemical properties even at temperatures below freezing. Lowest practical application temperature for other plastics generally is about + 5°C, but methacrylics can be applied to dry substrates at temperatures down to - 10°C.

5. Pot-lifes are sufficient for most purposes and the curing time extremely short, allowing full mechanical and chemical loads within 1-3 hours even at low temperatures. Repair and coating of concrete surfaces thus can be made very rapidly and down-time for such areas reduced to a minimum.

6. Perfect adhesion between new and old coats of methacrylic - this is important, as damage will occur, as everything earlier or later will come down on the floor - heavy iron ingots etc. Other plastics such as unsaturated polyesters, polyurethanes and epoxies must be thoroughly roughened in order to achieve adhesion between new and old coats, and the result may in spite of this be doubtful.

7. Cured MMA-resins are characterized by extremely good weatherability and ageing resistance. The mechanical strength is comparable with that of epoxies and polyurethanes. The resins may be formulated as hard and tough or soft and elastic.

8. The chemical resistance is good against alkalies, salts, dilute organic and inorganic acids, gasoline, oils, fats and a great number of other chemicals.

Photo 69

Photo 70

Photo 71

Photo 72

Photo 73

Photo 74

Photo 75

Photo 76

Photo 77

Photo 78

Grout and Stone Procedures for Small Craters

Purpose

95. The purpose of this field test of project REREPS was to evaluate the repair of small craters with various grout and stone procedures. Three small craters were to be repaired, each with a different technique and/or consistency of grout. Two of the repairs were patterned after a technique developed by the WES. The other technique used was patterned after one that local contractors use in the repair of roads. (This particular technique was brought to our attention by Herr Effinberger of the firm Nahe-Beton in Idar-Oberstein, FRG.) Not only was the "how" of the technique important, but also whether troops could perform the repair under field conditions.

Methodology

96. The two different repair techniques (one developed by the WES and the other developed by local German contractors) were used as guides for our repair techniques. A brief description of these two techniques follows:

a. WES technique. This technique consists of backfilling the crater with a washed gravel, 1-in. maximum size and uniformly graded up to within 15-18 in. of the top. Load transfer devices are then placed into position. A layer of sand and dry bentonite approximately 1 ft wide and 1-2 in. deep is then placed on the washed gravel around the entire edge of the crater. The gravel is then covered with two sheets of 6-mil polyethylene film to keep the grout from penetrating the washed gravel. Next, the crater is filled approximately one-third full with grout. A front-end loader then dumps and spreads limestone in the crater to within 1 in. of the top surface. The limestone is then compacted with a vibratory steel wheel roller. The remainder of the crater is then filled with grout and hand finished. The completed crater surface is then covered with a sheet of polyethylene to prevent surface moisture evaporation during curing.

b. German method. The German method consists of backfilling the crater with a washed gravel, 56-75 mm in size, flush with the existing surface of the surrounding concrete. The gravel is then lightly compacted. Grout is then placed on top of the gravel and worked down through by passing a vibratory roller over the surface. The final surface finish is then completed by hand.

97. There were two different consistencies of grout used. One grout consistency approximated the grout used by the WES. The other that was given to us by Herr Effinberger is the grout used by local German contractors.

a. The grout used by the WES consisted of Class A portland cement, flake calcium chloride, cement friction reducer, and water. The grout had a density of 120 pcf and contained the following percentages by weight: cement - 68, water - 31, calcium chloride - 1, and friction reducer - 0.2.

b. The grout used by German contractors consists of 450 kg of cement (PZ35F), 1800 kg of 0-2 mm sand, and 225 ℓ of water per 1 cu m.

Test site - construction of test craters

98. The Battalion's test site is located in Baumholder, Germany, just east of the Baumholder Army Airfield (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

99. The four large craters that currently exist in the pad have been used in previous semiannual training exercises. Prior to the exercise conducted on 13 November 1979, crater 1 contained crushed stone (0-32 mm); crater 2, BN 55 concrete; and crater 3, BN 25 concrete. These were the craters used during the test.

100. Crater 1 was prepared using a 2-1/2-yd scooploader. It was dug to a depth of 1 m and had a diameter of 6.5 m. Craters 2 and 3 were prepared by a D7F dozer. The depth and diameter of these craters approximated those of crater 1. Craters 1 and 2 had standing water. All craters had heaved sections of concrete and "in situ" material scattered about their edges.

Crater 1 - repair with German technique

101. Work on crater 1 commenced by having a 2-1/2-yd bucket loader clean all large sections of concrete and any unsuitable ejecta from around the crater edge and then push it all to the side of the runway. Then, a Davey 250-cfm air compressor was used to pump out the standing water. As soon as all the standing water had been pumped out, it was noted that water was entering the crater through the subgrade at a very steady rate. Work ceased at this point to allow the crater to again

fill with water. After approximately 45 min, the standing water (approximately 1 ft deep) was again pumped out. The flow of water through the subgrade was now noticeably slower. It was decided at this point to remove all saturated material in the crater and refill with a larger rock (56-75 mm) so that the repair of the crater could continue. Any water that did enter the crater from below would only fill the voids in the 56-75 mm rock and hopefully not cause any further problems with the repair (especially compaction). A 2-1/2-yd scooploader was used to remove the saturated material. The depth of the crater was now approximately 1.5 m.

102. In the following step, sufficient 56-75 mm aggregate was placed into the crater up to a level 0.9 m below the existing surrounding concrete. The normal repair sequence again started, with the addition of select aggregate, 0-32 mm in size, into the crater. Aggregate was added by a 2-1/2-yd loader from an existing stockpile nearby. (Note that the existing stockpile had been hauled to the repair site by 20-ton dump trucks.) The aggregate was placed in two lifts of 0.25 m per lift. Each lift was compacted by a towed, 7.5-ton airmobile vibratory roller. Minimum required compaction effort to be achieved was 95 percent. A compaction check of the top layer was made using the nuclear densimeter. A reading corresponding to 97.4 percent CE 55 was obtained (Table 5). It should be noted here that handwork was required to clean around the inside of the crater edge and to compact the aggregate at the edges using piston tampers. The level of the final aggregate lift was now 0.4 m below the existing surrounding concrete. Then, a Davey 250-cfm air compressor was used to provide compressed air to clean off the inside concrete face of the crater.

103. Next, two layers of polyethylene plastic sheeting was placed in the crater. On top of the plastic, 56-75 mm aggregate was added flush with the level of the existing surrounding concrete. Since this was a test, half of the aggregate surface was compacted, and the other half was not. A towed, 7.5-ton airmobile vibratory roller was used to make two passes over one half of the crater surface. The reason that half the surface area was compacted while the other half was not was to

see if this would have any effect on the depth of penetration of the grout. The crater was now ready to accept the grout. The grout used for this crater was the German grout (see paragraph 97 b for consistency). The grout was transported to the site in concrete transit ready-mix trucks. The truck backed up to the crater and placed its load of grout on the aggregate surface (Photos 79 and 80). (A small amount of water from the ready-mix truck had to be added to the grout mix to make it more fluid so that it would penetrate the aggregate layer.) Personnel used shovels to spread grout over any areas missed by the truck (Photos 81 and 82). A total of 7 cu m of grout was placed on the crater surface. The grout was worked down into the aggregate by passing a towed, 7.5-ton airmobile vibratory roller over the crater surface (Photos 83, 84, and 85). The vibratory roller made four passes over the entire crater surface. Personnel at times had to remove pieces of aggregate that protruded through the grout surface. Personnel also used wooden floats to finish the surface of the grout. After the surface was finished, the grout was allowed to cure. This step completed the repair on crater 1.

Crater 2 - repair with WES technique (variation 1)

104. The repair of crater 2 was the same as that of crater 1 up to and including the plastic being placed in the crater. (Note that the water in crater 2 was not as much of a problem as in crater 1. The water was pumped out, saturated material taken out, and select aggregate (0-32 mm) placed and compacted in lifts to a level 0.4 m below the existing, surrounding concrete.) After the plastic was put down, two thirds of the crater cap was filled with grout (Photo 86). The grout was the same consistency as the grout of crater 1. A 2-1/2-yd scooploader then added small amounts of 16-56 mm aggregate to the crater, working the aggregate and grout together by the actions of the wheels and bucket (Photos 87 and 88). Additionally, personnel also utilized shovels to work the aggregate and the grout together, especially near the edges of the crater (Photo 89). Once sufficient aggregate had been placed, personnel began to strike off the top surface of the crater with a piece of wood (2 x 4). Additional grout had to be added in spots to keep the aggregate and grout workability up. (This was provided from wheelbarrows

full of grout (Photo 90).) Finishing and curing proceeded the same as for crater 1.

Crater 3 - repair with WES technique (variation 2)

105. The repair of crater 3 proceeded in the same manner as that of craters 1 and 2 with the exception that since crater 3 was dry, no water had to be pumped out. Once plastic sheeting had been placed in the crater, two thirds of the crater cap was filled with grout (Photos 91, 92, 93, and 94). The grout was the same consistency as listed in paragraph 97 a with the exception that no calcium chloride was added. (Reason: the local German concrete supplier did not have any on supply when we required the grout.) After the grout had been placed in the crater, a 2-1/2-yd scooploader began to push a stockpile of 0-76 mm aggregate into the crater (Photo 95). As the loader pushed the aggregate in from one side, the volume of the aggregate added displaced an equal volume of grout, some of which overflowed the crater edge. The loader operator was instructed to ease the aggregate into the crater to prevent this (Photo 96). The loader also traversed through the grout and aggregate mixture in an attempt to work the two together (Photo 97). As it did, more grout spilled over the edges. The grout was very liquid and also very slippery due to its high-cement content. The grout spilling over the crater edges made it very difficult for the crater cap repair personnel to keep the crater edge defined. The loader continued to add aggregate and work the mix until sufficient aggregate had been added. The repair personnel then began to screed the repaired area flush with the existing surrounding concrete. This took quite a while as: (a) the edges were hard to define and (b) the mix was becoming somewhat stiff. The repair crew also used additional grout to maintain the workability of the mix (this was again stockpiled in wheelbarrows to cover this eventuality). Bullfloats and wooden hand floats were used to finish the surface and work the edges. Also, if any pieces of aggregate could not be worked down into the mix, they were removed.

Trafficking of test craters

106. Load cart. A load cart (Photos 15 and 16) was used to simulate the wheel load of an F-4 aircraft. The total weight over the F-4 wheel was 25,500 lb with a tire pressure equalling 286 psi.

107. Application of traffic. Application of traffic over the repaired craters was conducted 7 days after the repair was effected. The load cart was positioned in the center of the crater and passed 30 times across the crater. The passes were all in the same line. This was accomplished by stationing two ground guides (one in front and one in the rear of the truck) who directed the load cart back and forth across the crater.

108. Behavior of test craters. The results of passing the load cart over craters 2 and 3 were very satisfactory. There were no deflections or stress cracks observed. The results on crater 1 were not good. After only 10 passes, the top layer began breaking apart, and after 30 passes, a rut of 2-3 in. had developed. Also, large sections of the grout and stone were beginning to break away.

Analysis of results and conclusions

109. Analysis of results. The crater repair on crater 1 using the German method was not very satisfactory. Some of the problems and potential reasons are:

a. It was learned after the repair had been completed that inadvertently the 56-75 mm rock had been mixed with some 0-32 mm aggregate on site. These fines acted to "choke off" the grout from penetrating the correct distance into the rock and thus caused the grout to remain in a very thin layer on top. Consequently, the grout cracked easily under load as there was not the proper balance of large aggregate present in the top layer.

b. The problem of getting good compaction on the subgrade was not really achieved here due to the water entering the crater. The large rock was added so that we might proceed with the repair technique. This water in the bottom of the crater could very definitely have a detrimental effect on the life expectancy of any crater cap.

110. On craters 2 and 3, the WES technique was modified and the crater cap filled two-thirds full of grout initially, then rock added. This, as it turned out, was too much because as rock was added, grout

would spill out. Also, it was extremely difficult and messy to keep the crater edge defined. The use of the loader bucket proved more valuable in obtaining a better grout/aggregate mix than by just running the loader wheels through the mixture. The noncommissioned officer in charge (NCOIC) of crater 2 repair crew utilized this method with very good results. The repair crew of crater 3 used the loader wheels strictly and consequently took longer to repair the same size crater.

111. There was no noticeable difference in the amount of penetration of grout through the aggregate in crater 1 between the compacted aggregate side and the uncompacted aggregate side. Again, since there was 0-32 mm aggregate mixed in with the 56-75 mm aggregate, it in effect "choked off" the grout.

112. Both grout consistencies were easy to work with, as were the methods to employ them. This was not a timed exercise, but the repair went surprisingly fast, considering this was the Battalion's first attempt at this method.

113. Conclusions. Based on the results obtained, the conclusions that can be reached are:

- a. All methods and consistencies of grout appear to offer satisfactory results. (Note that the German method will again be tested with the correct size aggregate before concluding definitely on the method's reliability.)
- b. The methods are suitable for troops.
- c. The WES grout is very expensive (DM 280 per cubic meter or $150). This is two to three times more expensive than regular concrete. The German grout is DM 146 per cubic meter or $75.
- d. Utilizing the 2-1/2-yd loader four-in-one bucket seems to do a better job of mixing the grout and aggregate together than just using the loader tires. Using both bucket and tires works even better.
- e. Filling the crater cap two-thirds full of grout is too much. Using one third (what the WES used) would be more suitable, especially when the grout is so fluid.

The 293rd is scheduled to retest the German method and the WES method once more in spring 1980. This will provide a better feel for the feasibility of this method. It will also be timed.

Table 5

RERЕPS Density Tests (13 November 1979)

Test No.	% w	γ_d	% Compaction
1	8.50	132.20	103.50
2	8.50	125.48	98.30
3	8.50	124.38	97.40
4	8.50	128.77	100.80
5	8.50	126.30	98.90

Reading Time/Test - 1 or 2 min   Testing Depth - 6 in.

Remarks

Material tested was 0-32 mm gravel.

Tests 1 and 2 were conducted on crater 3. Compaction value was 100.9 percent.

Test 3 was conducted on crater 1. Compaction value was 97.4 percent.

Tests 4 and 5 were done on crater 2. Compaction value was 99.9 percent.

Minimum required percent compaction was 95. Water content at 8.5 percent is only an estimation. Maximum dry unit weight was 127.7 pcf.

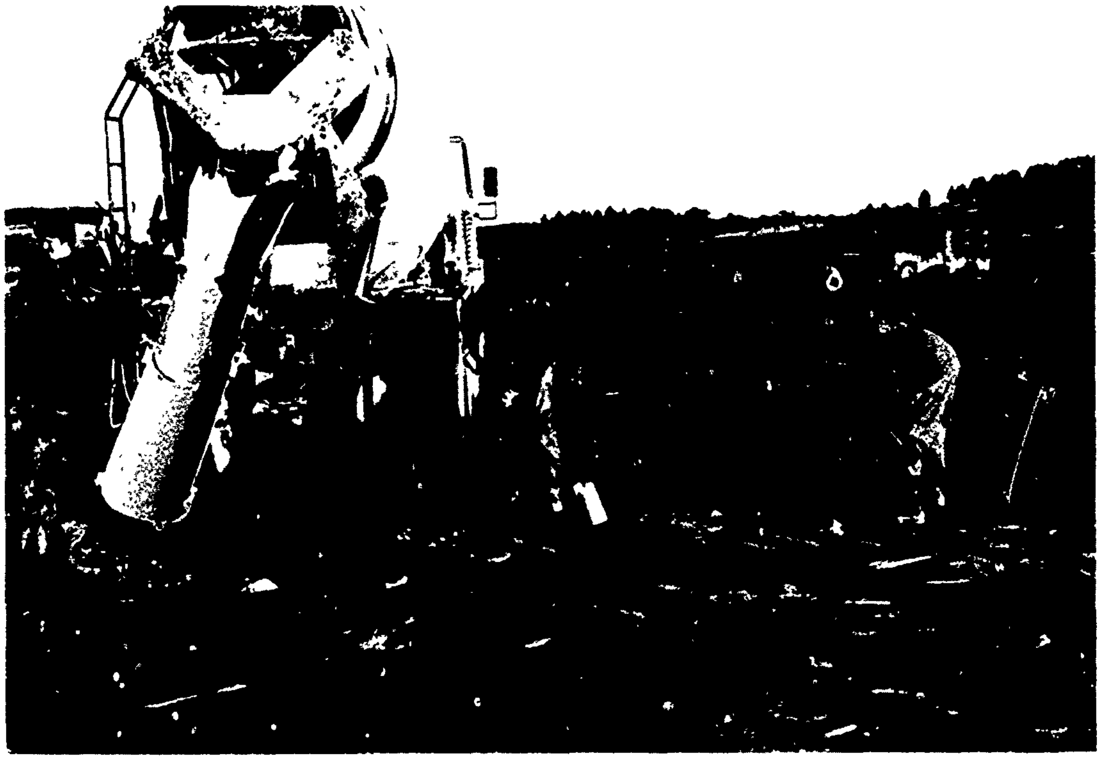


Photo 79

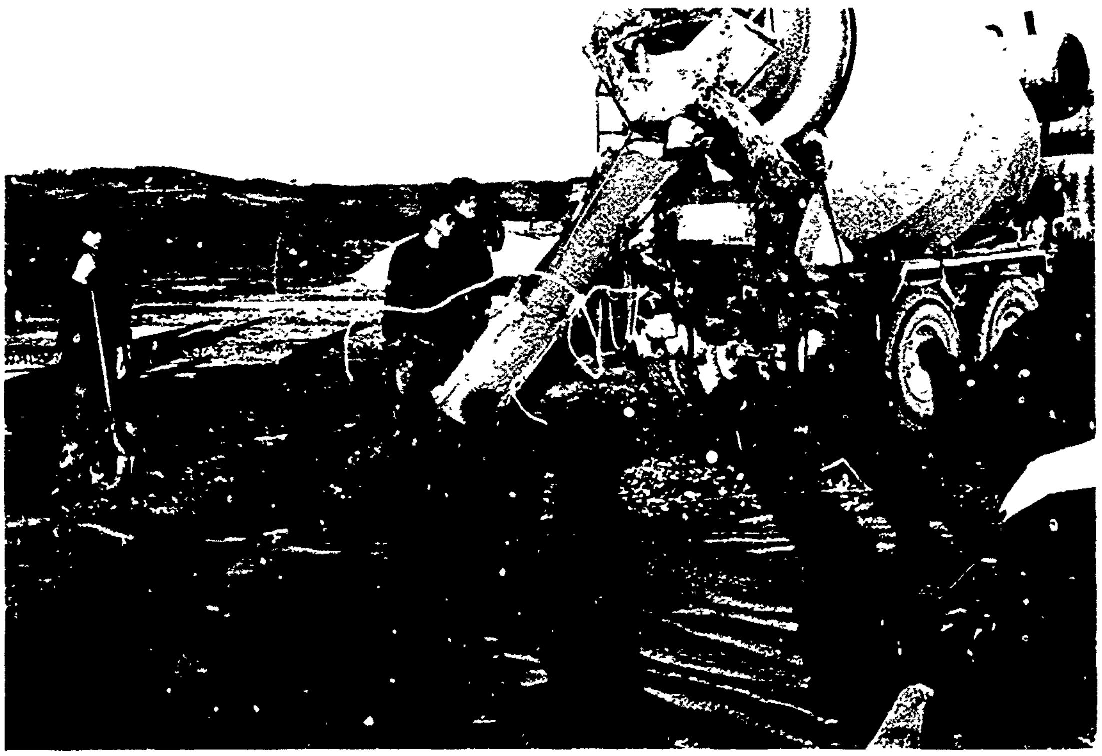


Photo 80

Photo 81

Photo 82

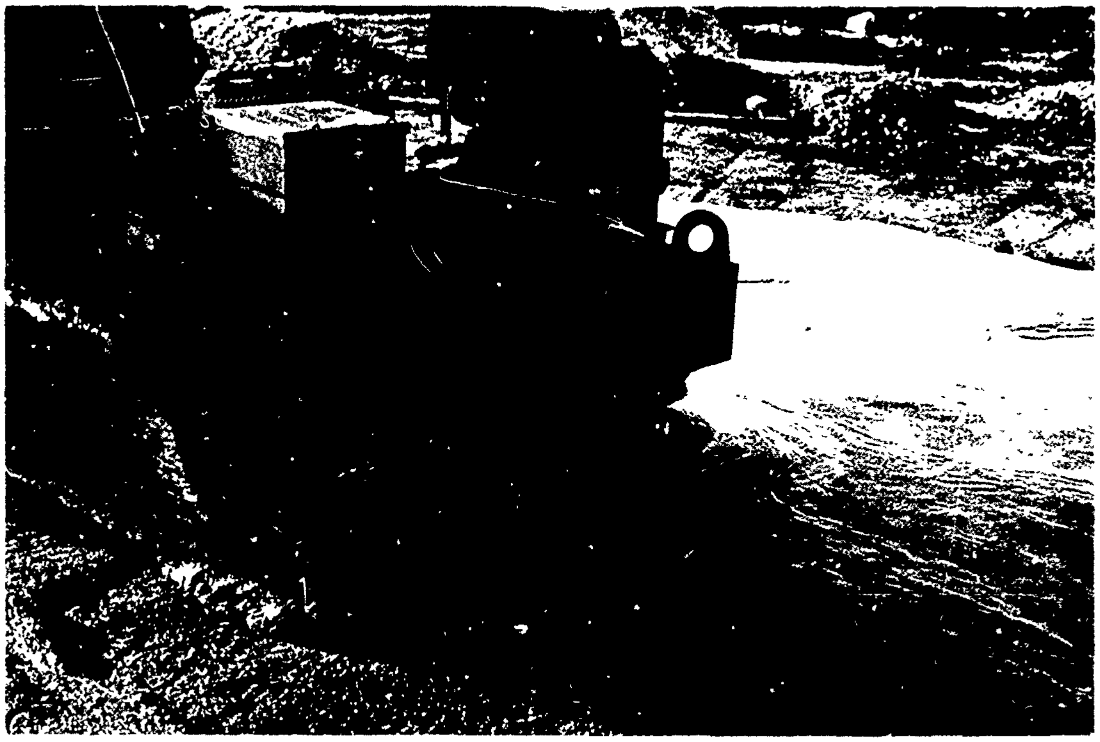


Photo 83

Photo 84

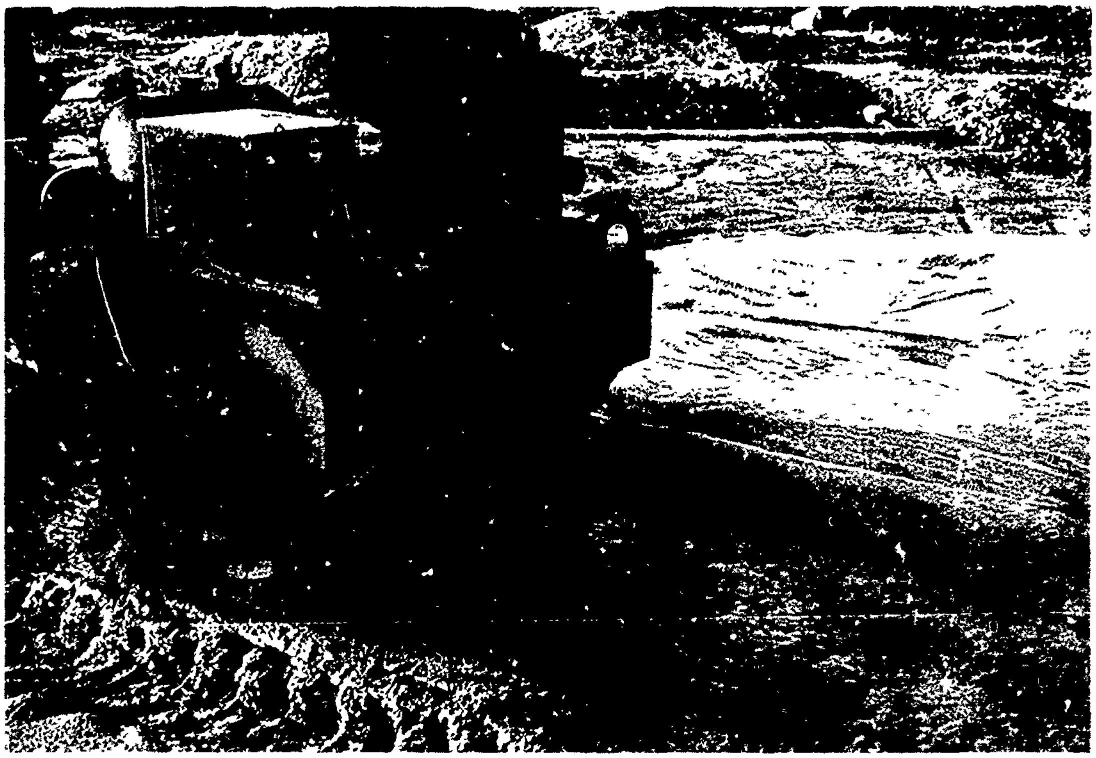


Photo 85

Photo 86

Photo 87

Photo 88

Photo 89

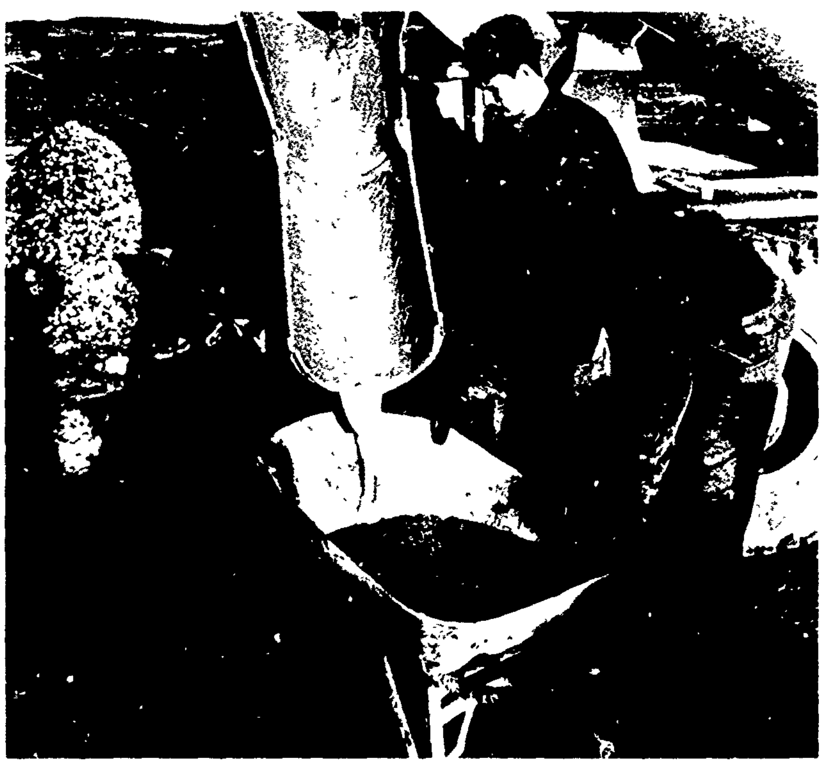


Photo 90

Photo 91

Photo 92

Photo 93

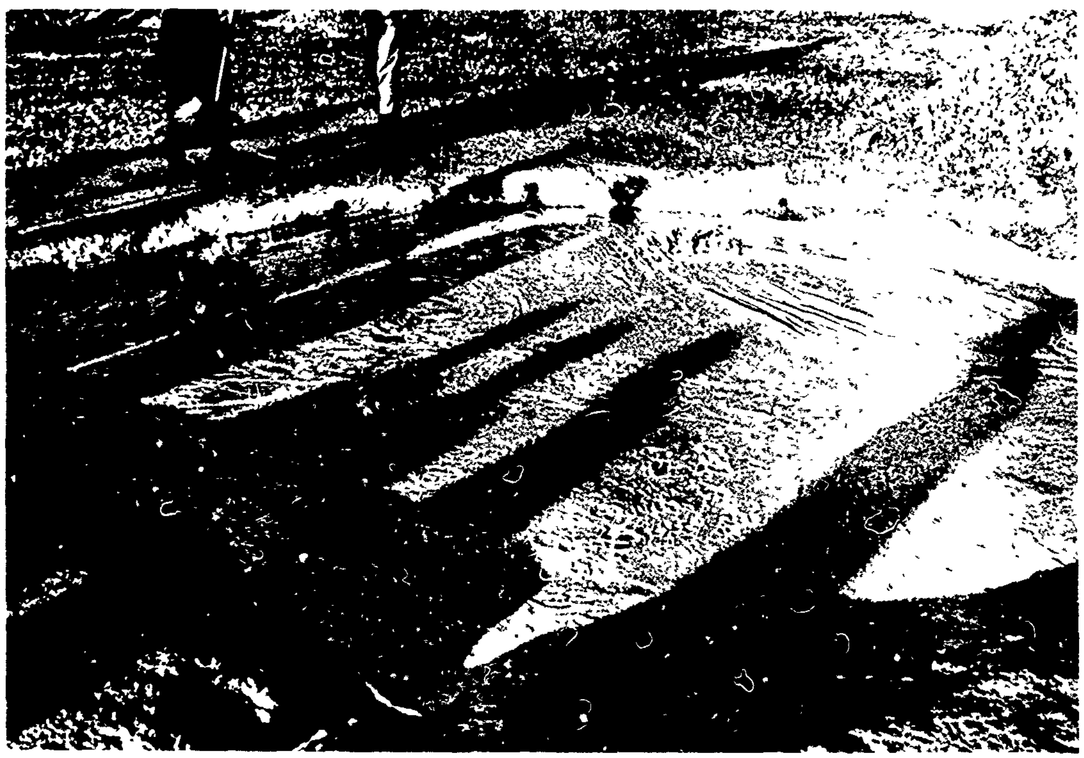


Photo 94


Photo 95


Photo 96

Photo 97

Hot-Mix Asphalt for Large and Small Craters

Purpose

114. The purpose of this field test of project REREPS was to evaluate the adequacy of the repair of both large and small bomb craters utilizing hot-mix asphalt as the capping material. This unit has previously conducted repairs of bomb damaged craters with asphalt, but little, if any, performance data had been recorded on the adequacy of the repair. The last time this unit conducted repair with asphalt was in 1977. These field tests would then not only provide us with performance data but also familiarize the personnel performing the repair with the technique. Two separate field tests were conducted on different days: (a) on 2 April 1980, a large crater was repaired with an asphalt cap; and (b) on 9 April 1980, two small craters were repaired, again with asphalt caps.

Methodology

115. The methodology employed in the repair of both the small and large craters is essentially the same as with any other crater repair utilizing crushed stone as the base material. The design for the flexible pavement is dependent on the type of aircraft for which the runway is designed. (Inclosure 1 details the design criteria used and presents sketches of the minimum required design thicknesses.) For the repairs conducted, the following procedure was used. The crater was prepared in the same manner as any other crater until a depth of 28 in. below the existing runway was obtained. All material at and below this level was suitable crater ejecta that had been compacted to 85 percent CE 55. Next, two 12-in. lifts of well-graded aggregate, 0-32 mm in gradation, were added with each lift being compacted to 100 percent CE 55. This then left 4 in. for the asphaltic concrete cap. The next step was to spray a prime coat on the top layer of rock using a bituminous emulsion (U-60) or a cutback asphalt (P-66). Following this step, the asphalt was placed, spread, and compacted in one lift of 4 in. (It should be noted that the compacted thickness of the cap is required to be 4 in., so the asphalt was overburdened by 1 to 1-1/2 in. in the uncompacted

state prior to breakdown rolling.) Breakdown rolling on large and small craters differed slightly. For the small crater, the breakdown roller made straight passes across the crater in the same direction as the runway. For the large crater, the crater edge was rolled first in a circular pattern for one pass to keep the crater edge identified before the asphalt got too cold. Then, the breakdown roller proceeded across the crater parallel to the main axis of the runway, the same as for the small crater. Following the breakdown roller (after sufficient time for cooling of the asphalt), the nine-wheel pneumatic tire roller was placed on the surface to further compact the cap. Once this was complete, the finishing roller made several passes over the repaired cap. As in other crater repair exercises, the runway surface was then swept to prevent FOD to aircraft and/or engines. Figure 19 depicts a cross-sectional view of a completed crater repair.

Test site -
<u>construction of test craters</u>

116. The Battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

117. The craters were constructed using a D7F crawler tractor. The large crater was approximately 20 m in diameter and 3 m deep. The small craters were approximately 6 m in diameter and 1 m deep. Ejecta was mounded around the edges of the craters simulating a bomb explosion.

<u>Asphalt repair</u>

118. <u>Crater preparation</u>. Crater preparation proceeded for the large crater as follows. First, a 5-yd loader and D7F dozer in combination cleared the debris and unsuitable ejecta from around and within the crater. The dozer then began to traverse back and forth across the crater compacting the suitable ejecta to 85 percent CE 55. Once this was completed, two lifts of 0-32 mm aggregate (23 in. thick) were added, and each was compacted to 100 percent CE 55. The top surface of rock was then left 4 in. below the existing surrounding runway surface. Personnel with shovels and brooms cleaned the small loose pieces of

concrete or any dirt from around the edges to ensure that a good bond could be obtained between the new asphalt cap and the old concrete crater edge. The crater was then prepared for the asphalt cap. Total repair time to this point was 2-1/2 hr.

119. In essentially the same manner as for the large crater, crater preparation proceeded on the two small craters. The only difference was the use of smaller equipment when cleaning around and in the crater. Instead of 5-yd loaders and D7F dozers, 2-1/2-yd loaders and backhoes, John Deere Model JD410, were used. Also, there was more handwork involved (i.e., personnel with picks and shovels) than for the large crater. One other major difference must be noted here. On one of the small craters, there was subsurface water constantly coming into the crater from below. So, instead of using 24 in. of 0-32 mm aggregate as the base above the ejecta, a reinforced earth technique was used in combination with the aggregate to give a stronger base. This involved placing two layers of logs (8 in. in diameter) directly over the ejecta, followed by placing 8 in. of aggregate on the logs and compacting to 100 percent CE 55. (Figure 20a shows a cross-sectional view of this technique, and Figure 20b a cross-sectional view of standard asphalt cap repair.) Once the rock was added in both craters at a level 4 in. from the top, the craters were ready to have the asphalt cap placed. Total repair time for the crater with logs to this point was 2 hr and 20 min. (The major reason for the difference is the time it took to cut and place the logs in the crater.)

120. Asphalt cap repair. The asphalt cap repair began by spraying an asphaltic emulsion (U-60) as a prime coat on the aggregate base. An asphalt kettle with hand-held spray bar was used. A suggested application rate of 0.2 to 0.3 gal/sq yd should be used; however, since the kettles were not calibrated or metered, the area was coated so that all areas were covered, with no excess "puddling" taking place. Once the prime coat had been placed, asphalt was back-dumped into the crater For the large crater, 78 metric tons (MT) of 0-32 mm asphalt was used. Asphalt was delivered to the training site by local German contractors in three trucks. (Price paid per MT was $31.) The temperature of the

asphalt mix when delivered was 320°-330°F. The asphalt sat onsite for 45 min before being used, while the prime coat was being placed. Temperature of the asphalt when placed was 250°F. Asphalt was dumped into the large crater, as shown in Figure 21.

121. Once the asphalt was dumped, a CAT 120 road grader was utilized to spread and level the piles. The particular grader operator had never spread asphalt before, and consequently, this operation took longer than expected. Personnel were also used to even out areas near the edges. The asphalt was slightly overbuilt to compensate for compaction. The spreading of asphalt by the grader took approximately 40 min. Once the asphalt had been spread and leveled, a 10-14 ton steel wheel roller (Hyster Model C350BD) made one complete pass around the outside edge of the crater to break down the asphalt and define the edge. The roller then started to make complete passes over the asphalt surface parallel to the runway center line. Several initial problems which were quickly corrected were the number of passes and the direction of movement that the roller made. Only one pass across the asphalt surface is required in the direction of the runway center line by the 10-14 ton roller. The roller operator had not been given specific instructions as to what to do, so he started by making more than one pass across each area and in more than one direction. However, when given the necessary instructions, the operator began the correct rolling procedure. After the breakdown rolling was completed, a nine-wheel pneumatic roller (Hyster Model C530A) was placed on the asphalt surface to further compact it. (Note that the nine-wheel roller should be placed on the surface after the asphalt has cooled slightly, but before the temperature reaches 185°F. A good rule of thumb is to wait until you can hold your hand over the mat for 3 sec without it getting too hot.) The nine-wheel roller makes passes in the same direction as the breakdown roller. Following the nine-wheel roller, the finish roller (10-14 ton steel wheel) places the finish on the asphalt cap. The roller is placed on the surface while the mix is still warm so that any roller marks can be removed. For all rolling, if the roller does not make any sharp turns on the surface, roller marks and the possible

shifting of the mat can be reduced. (It is recommended that all rolling be completed within 15 min after spreading for a 4-in. lift.) Once the finish roller made its passes, the asphalt cap repair for the large crater was completed. Total time to place the asphalt cap was 1 hr.

122. The same repair technique was used for both of the small crater repairs. Twenty-one metric tons of 0-8 mm asphalt was used for both craters (about 10.5 MT per crater). Total repair time per crater for placing the asphalt cap was 40 min. (Note that one crater was repaired at a time because of equipment limitations--only one grader, one 10-14 ton roller, and one nine-wheel roller onsite.)

123. Runway cleanup. As with any other runway repair, the surface of the runway must be swept clean of any foreign objects (stones, dirt, etc.) that could be ingested by an airplane engine and cause serious damage. Following the completion of placing the asphalt cap, a rotary sweeper towed by a jeep was used to clean the runway surface.

Trafficking of test craters

124. Load cart. A load cart (Photos 15 and 16) was used to simulate the wheel load (front landing gear) of an F-4 aircraft. The total weight over the F-4 wheel was 25,500 lb with a tire pressure equalling 286 psi.

125. Application of traffic. The load cart was positioned in the center of the craters and passed across by backing up the vehicle. All passes on the large crater were made in the same lane. Two ground guides (one in front and one in the rear of the truck) guided the load cart back and forth across the crater. Traffic was not applied to the large crater for 6 days after the cap was placed because the load cart was nonoperational during that time. Normally, the cart was loaded 48 hr after the completion of repair. Passes were made on the small crater repairs 2 days later. One small crater had 100 passes of the load cart in five lanes of 20 passes each (Figure 22), while the other crater had only 20 passes over the center area. The crater with 100 passes was the crater that utilized the reinforced earth (logs) technique as the base under the asphalt cap.

126. Behavior of test craters. Since 6 days had passed since the

completion of the asphalt cap repair and the application of traffic, truly valid results for this particular repair cap could not be obtained. However, some observations are recorded here. Over the 6 days, various wheeled vehicles had traversed the crater cap. There were no failed areas, although the asphalt had densified slightly in a few areas. The overall surface was intact and was holding up well. The load cart did not densify the asphalt cap in any spots. The edges were slightly rough but offered no problem for aircraft wheels because of the 0-32 mm size asphalt used.

127. The small craters reacted basically the same as the large crater. After 100 passes on the small crater, which used logs as part of the base, a slight dip was created in the asphalt surface by the load cart. The rolling dip was not severe and would not have interfered with aircraft operations. The other small crater cap performed well. No noticeable defections were created by the load cart, although only 20 passes were made across the repaired area.

Analysis of results and conclusions

128. Analysis of results. The best performing cap of the three crater repairs was the small asphalt that strictly used 28 in. of 0-32 mm aggregate as the base. The other small asphalt cap repair performed exceedingly well, considering that particular crater had a subsurface water problem. Previous repairs with crushed stone on that very crater have not performed well because of the water being pumped to the surface when trying to obtain the required compaction. The slight dip could have been created in that area because of the asphalt densifying or the base rock being pushed through the separations between the logs, thereby creating a void into which the overlaying asphalt could have been compressed. The large crater repair did densify in spots, but not seriously.

129. Conclusions. The conclusions that were reached concerning the repairs with asphalt are:

a. The grader operator that spreads and levels the asphalt must be experienced. This process is possibly the most important in conjunction with the base preparation to ensure a quality, reliable repair if obtained.

b. The base preparation must be compacted to standards. Failure to meet the compaction requirements results in base failure and hence densification of the asphalt cap, thereby causing ruts.

c. Edges must be cleaned and well defined. Excess asphalt spread over the edge breaks up very easily and could result in FOD to aircraft.

d. WES engineers have conducted tests with hot-mix asphalt. They have been successful with their caps using this material. Thus, in a wartime environment, it is felt that this mix will be a suitable capping material and will give an adequate performance.

Inclosure 1

1. References:

a. TM 5-330, "Planning and Design of Roads, Air Bases and Heliports in the Theater of Operations,' September 1968.

b. TM 5-824-2/AFM 88-6, Chap. 2, "Airfield Flexible Pavements - Air Force," February 1969.

2. The basis for the design of an asphalt cap is the CBR (California Bearing Ratio) value of the underlying base courses. In order to determine the proper design required, certain assumptions must be made. The first assumptions are the CBR values of the subgrade, select fill, and base courses. The field CBR values that can be expected for the following types of soil, as given in TM 5-330, are:

GW - well-graded gravel	-	CBR 60 to 80
GP - poorly graded gravel	-	CBR 25 to 60
GM - silty gravel	-	CBR 40 to 80
GC - clayey gravel	-	CBR 20 to 40
SW - well-graded sand	-	CBR 20 to 40
SP - poorly graded sand	-	CBR 10 to 25
SM - silty sand	-	CBR 20 to 40
SC - clayey sand	-	CBR 10 to 20
OL - silts and clays	-	CBR 3 to 8

From these field values, the following average CBR values are assumed for purposes of design:

SUBGRADE - CBR 5
SELECT FILL - CBR 30
BASE COURSE - CBR 70

The values represent the average CBR that can be expected at 90 percent modified AASHO compaction from the variety of soils that might be encountered when repairing damaged runways.

3. Using these CBR values and the design curves from Appendix D, TM 5-330, a required thickness of asphalt, base course, and select fill can be obtained.

4. Additional criteria used in the design of a crater cap are as follows:

a. All caps are designed for fully operational air traffic. That is, the pavement will support traffic equivalent to 1000 coverages with only moderate maintenance.

b. No structural layer except the pavement shall be less than 6 in. thick.

c. No pavement layer shall be less than 1 in. thick. Such layers are subject to being pushed up by high-velocity jet blast.

5. Attached are sample designs for various aircraft presently deployed in the European theater of operations. All depths of base layers are minimum depths.

Type of Aircraft: C130 Cargo

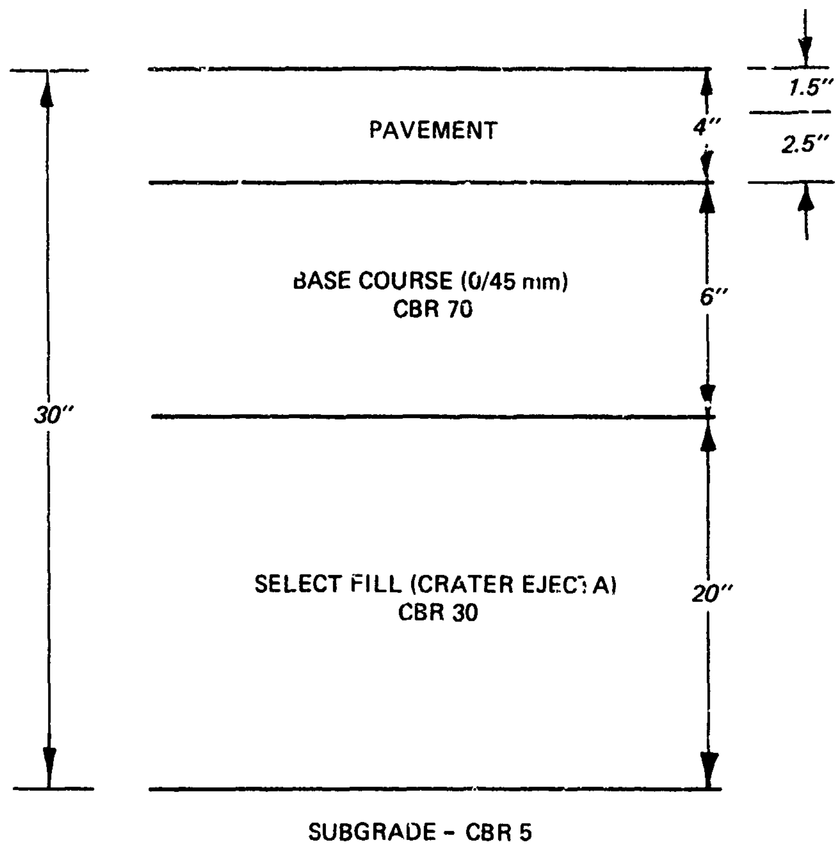
Maximum Take-off Weight: 175 kips

Design Load - Main Landing Gear: 83.8 kips

Tire Pressure: 95 psi

Contact Area: 440 sq in.

Design Curve: D-30, page D-31, TM 5-330



Type of Aircraft: C141 Cargo

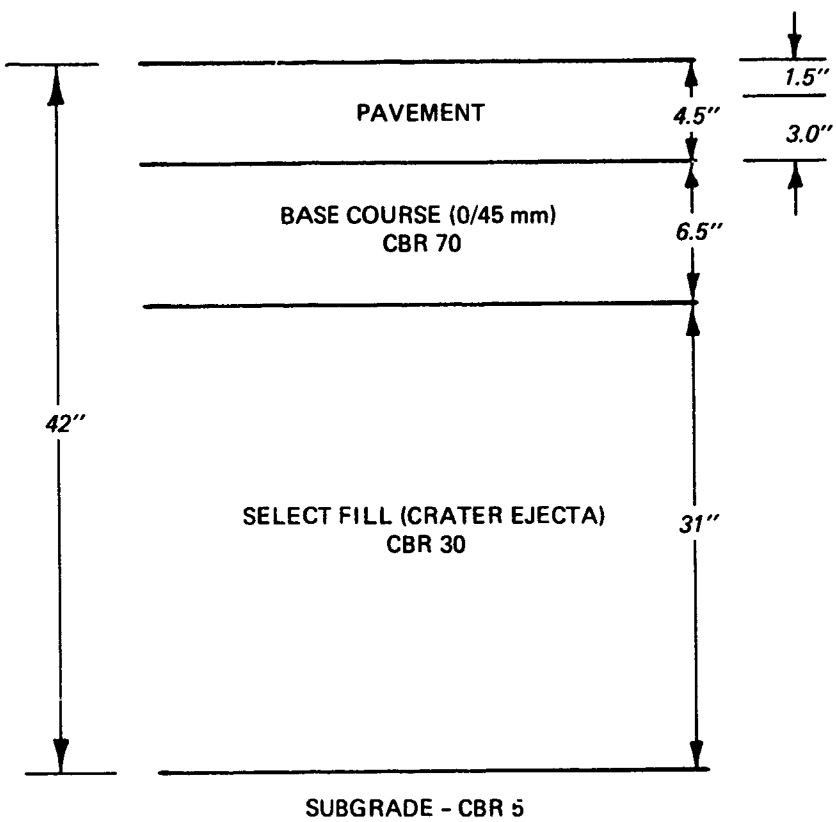
Maximum Take-off Weight: 316.6 kips

Design Load - Main Landing Gear: 149.5 kips

Tire Pressure: 180 psi

Contact Area: 208 sq in.

Design Curve: D-36, page D-37, TM 5-330



Type of Aircraft: C5A Cargo

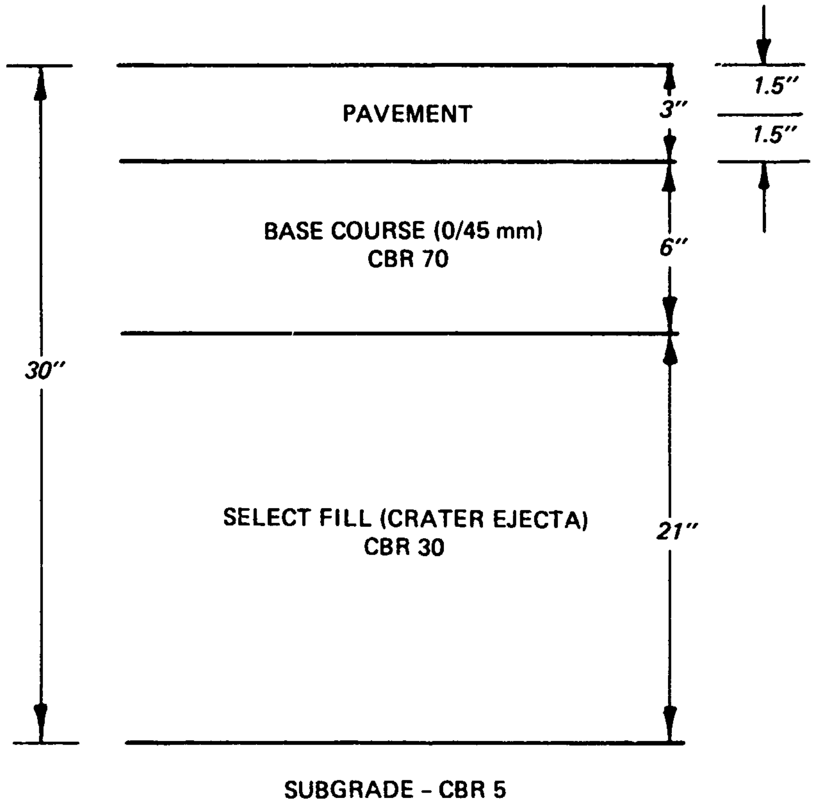
Maximum Take-off Weight: 769 kips

Design Load - Main Landing Gear: 199.8 kips

Tire Pressure: 115 psi

Contact Area: 190 sq in.

Design Curve: D-43, page D-43, TM 5-330



Type of Aircraft: F4C Fighter

Maximum Take-off Weight: 59.1 kips

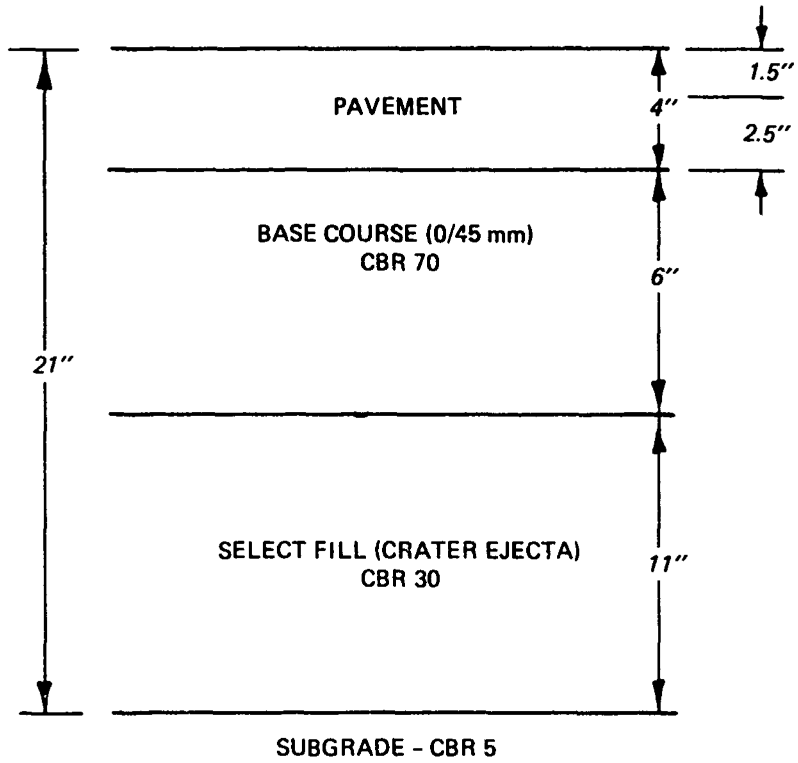
Design Load - Main Landing Gear: 26.0 kips

Tire Pressure: 255 psi

Contact Area: 129 sq in.

Cycles: 13,450

Design Curve: D-27, page D-28, TM 5-330



Cross Section of Completed Crater Repair with Hot-Mix Asphalt

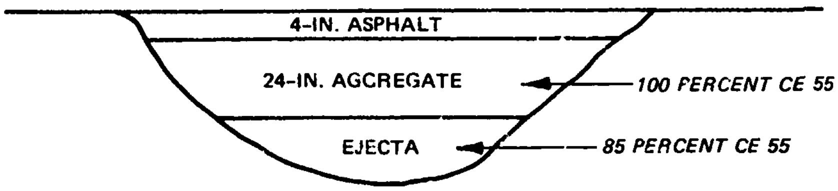
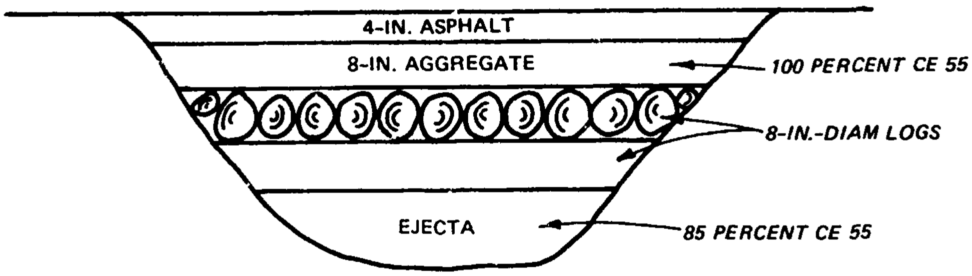
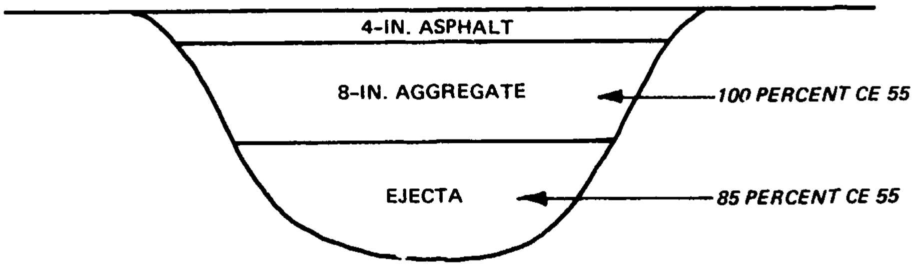


Figure 19

Cross Sections of Crater Preparation Methods



a. Reinforced Earth Technique with Aggregate



b. Asphalt Cap Repair

Figure 20

Asphalt as Dumped into
Large Crater

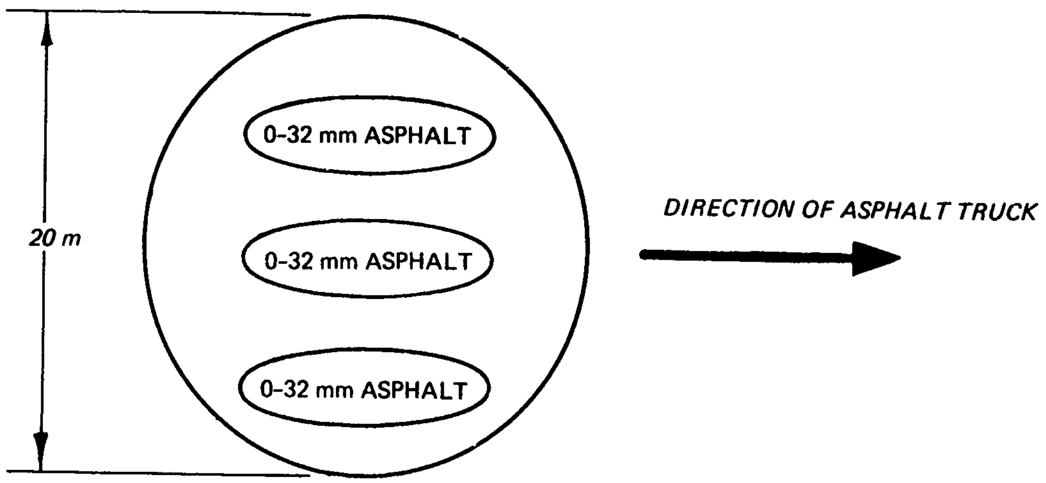


Figure 21

Passes of Load Cart
on Small Crater

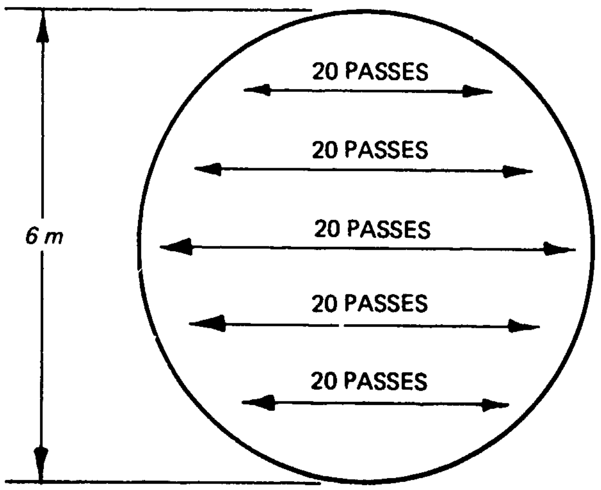


Figure 22

Reinforced Earth Concept for Small Craters

Purpose

130. The purpose of this field test of project REREPS was to evaluate the performance of a repaired crater utilizing a reinforced earth technique, specifically the addition of logs to strengthen (reinforce) the crater bowl. Additionally, it was necessary to see if this repair method was suitable for troops. Since this unit had never before conducted crater repairs in this manner, this training provided the opportunity to experiment with some new techniques.

Background

131. The use or concept of reinforced earth is not new to the construction industry. It is, however, the application of this technique to crater repairs that is new. This unit first learned of the work that Dr. George Hammitt of the WES in Vicksburg, Mississippi, was conducting with reinforced earth on a visit to the WES by LTC Theodore G. Stroup, the 293rd Engineer Combat Battalion Commander, in January 1980. Dr. Hammitt had been conducting various tests utilizing various forms of reinforced earth ranging from membranes to rock gabions to log cribs within the crater bowl in different configurations to determine if the crater performance could be improved while at the same time keeping the repair simplified. Based on Dr. Hammitt's and LTC Stroup's recommendations, it was decided to repair several small craters with logs being placed in the crater bowl to reinforce the earth.

Methodology

132. The following methodology was used for the repair of the two craters. The crater is prepared in the same manner as for any other repair. A 2-1/2-yd loader and a backhoe, John Deere Model JD410, are used to clear the debris from within and around the crater. Personnel with shovels, picks, and brooms also are needed to clear the loose sections of concrete and any dirt from around and under the crater edge. The crater is then cleaned and leveled to a depth 28 in. below the existing runway surface. This layer is compacted with hand tampers to 85 percent CE 55. A layer of 8-in.-diam logs is then placed on the

compacted ejecta layer totally covering the surface (logs placed as close to each other as possible). A second layer of logs is placed on the first layer in a direction perpendicular to the first layer. Again, the entire area is covered with the logs being placed side by side. Once the logs are in place, 12 in. of select fill (0-32 mm aggregate) is added and compacted to 100 percent CE 55 with a 30-ton vibratory roller. This step completes the crater repair. It must be noted that any type of cap material can be used. The type cap (i.e., concrete, asphalt, grout, and stone or crushed stone) and crater depth will determine the depth to place the logs. Figures 23 through 26 depict cross-sectional views of different types of caps.

133. This report covers two separate field tests conducted on different days. On 2 April 1980, a small crater was repaired utilizing logs to reinforce the earth in the crater bowl and a crushed stone cap. On 10 April 1980 a small crater was repaired, again with logs in the crater bowl, but this time an asphalt cap was used.

Test site - construction of craters

134. The battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Nineth metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

135. The craters were constructed using a D7F crawler tractor and were approximately 6 m in diameter and 1.5 m deep. Ejecta was mounded around the edges of the craters simulating a bomb explosion.

Crater repair

136. Crater preparation. Crater preparation for both of the small craters proceeded as follows. Two and one-half-yard bucket loaders and backhoes, John Deere Model JD410, cleared all ejecta and unsuitable debris from around and within the crater until a depth of 28 in. from the top (existing runway surface) was obtained.

137. Reinforced earth repair. Normally, the next step in the repair is to level and compact the subgrade to 85 percent CE 55. In both of the craters, water was continually entering the crater through the subgrade. Any compaction placed upon this layer only aggravated

the situation. Therefore, no compaction was applied. It was felt that the logs would act as a bridge over the soft spots anyway. Therefore, the first layer of logs was placed on the subgrade. The logs, approximately 8 to 12 in. in diameter (old telephone poles obtained locally), had been hauled to the site by a lowbed trailer. The trailer was pulled right next to the crater and personnel off-loaded and placed them by hand. Most of the logs had been precut to fit the crater the day before; however, a chainsaw was used to trim several that were slightly too long. The logs were placed as close together as possible. Personnel with picks and shovels had to dig under the ends of several of the logs in order to get them level. Once the first layer was placed, a second layer of logs was placed on top of the first layer and perpendicular to it. Again, the logs were placed next to each other. During the exercise on 2 April 1980, the repair crew ran out of logs before the second layer was completed. Approximately 5 ft remained to complete the second layer. Since no more logs were available, the repair sequence continued with the addition of 12 in. of 0-32 mm aggregate. Before the aggregate was added to the crater being repaired on 10 April 1980, a 5-yd loader was used to seat the logs because several of the logs were sticking up too high. It was felt that placing a heavy wheeled vehicle on them might help to compress them slightly. The 5-yd loader passed across the logs several times and did in fact seat the logs a few inches. Again, as in the 2 April exercise, 0-32 mm aggregate was added.

138. Crater cap. A 12-in. crushed stone crater cap was used in the 2 April exercise, while a 4-in. asphalt cap was used in the 10 April exercise. The 12-in. crushed stone cap was placed directly on the second layer of logs in one lift. It was placed by dumping aggregate from the bucket of a 5-yd loader, leveled with a grader, and compacted with a 30-ton vibratory roller (Tampo Model RS-20) until 100 percent CE 55 was achieved.

139. Since the crater cap on the crater that was repaired on 10 April was asphalt, only 8 in. of 0-32 mm aggregate was placed on the logs, with 4 in. for the asphalt cap. Again, it was placed in one lift

by dumping aggregate from the bucket of a 5-yd loader, leveled by personnel using shovels, and compacted by a towed 7.5-ton vibratory roller to 100 percent CE 55. Personnel using hand tampers compacted the aggregate around the edges. This layer was then sprayed with U-60, and the asphalt was placed, leveled, and compacted (see paragraphs 115-127).

140. Runway cleanup. As with any other runway repair, the surface of the runway must be swept clean of any foreign objects (stones, dirt, etc.) that could be ingested by an airplane engine and cause serious damage. Following the completing of placing the crater cap, a rotary sweeper towed by a jeep was used to clean the runway surface (Photo 47).

Trafficking of test craters

141. Load cart. A load cart (Photos 15 and 16) was used to simulate the wheel load (front landing gear) of an F-4 aircraft. The total weight over the F-4 wheel was 25,500 lb with a tire pressure equalling 286 psi.

142. Application of traffic. The load cart was positioned in the center of the craters and passed across by backing up the vehicle. Ground guides were used (one in front and one in the rear of the vehicle) to ensure that the load cart stayed in the same lane as it traversed back and forth across the crater. No tests were made on the crushed stone cap on April 2 as the load cart was nonoperational on that day. The small crater was tested on 10 April, however. A total of 100 passes of the load cart in five lanes of 20 passes each was made.

143. Behavior of test craters. After 100 passes of the load cart, a slight dip was created in the asphalt surface. The rolling dip was not severe and would not have interfered with aircraft operations. The crushed stone crater was not trafficked with the load cart, but on 2 April after the repair was completed, a 30-ton asphalt truck rolled over the surface as it was backing up to get in position to dump asphalt in a large crater that was also being repaired that day. No noticeable deflection was created in the surface, only the tread design of the tires.

Analysis of results and conclusions

144. Analysis of results. Inclosure 2 shows the times taken to complete the repairs of both craters. As noted, they are both very fast and fall well within the 4-hr time criteria. Both crater caps also performed exceedingly well. Even though the crushed stone cap was not tested with the load cart, promising results were obtained after a loaded 30-ton asphalt truck rolled over the surface. Granted, that the same loading criteria were not used, these results are a good sign because previous repairs on that crater with crushed stone alone (no logs added to reinforce the earth) have given miserable results. Also, it is believed that these results are directly attributable to the logs serving as a bridge over the weak spots in the subgrade caused by the standing water in the bottom of the crater. This fact was shown in the performance of the asphalt cap for the 10 April repair because that crater, which was the same one repaired in the 2 April exercise, too had water standing in the bottom. The rolling dip that was created was possibly the result of the asphalt cap densifying as part of the base aggregate was being pushed downward through the logs.

145. Conclusions. The conclusions that were reached are:

a. Reinforced earth technique using logs in the crater bowl appears to offer good potential in crater repair, but should not be considered a permanent type of repair. Its applicability should be considered for moist or saturated soil conditions in the crater bowl or where sufficient backfill (ejecta or quality fill) is not available.

b. Logs are a cheap, plentiful material that is easily used by troops.

c. Leveling of a subgrade is important to enable the logs to lay flat and prevent many voids.

d. Precutting of logs in various lengths from 2 to 10 m saves time in the repair. However, a chainsaw is definitely needed onsite to make on-the-spot adjustments.

Inclosure 2

TIMES FOR REPAIR

Small Crater - 2 April 1980

Start	0740 hr
Clear Debris	0820 hr
Place Logs	0920 hr
Place Cap (Crushed Stone)	1015 hr
	TOTAL 2 hr 35 min

Small Crater - 10 April 1980

Start	0810 hr
Clear Debris	0930 hr
Place Logs	1030 hr
Place Cap (Asphalt)	1210 hr
	TOTAL 4 hr

Average time: 3 hr 17 min

Concrete Cap

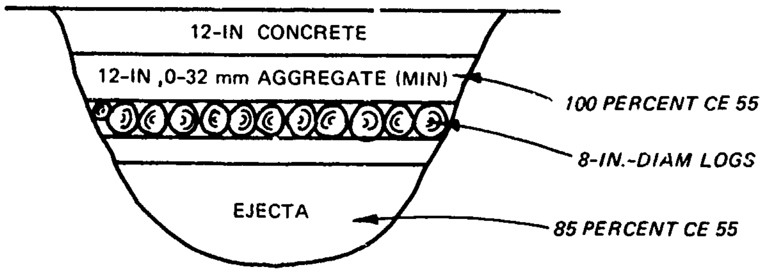


Figure 23

Asphalt Cap

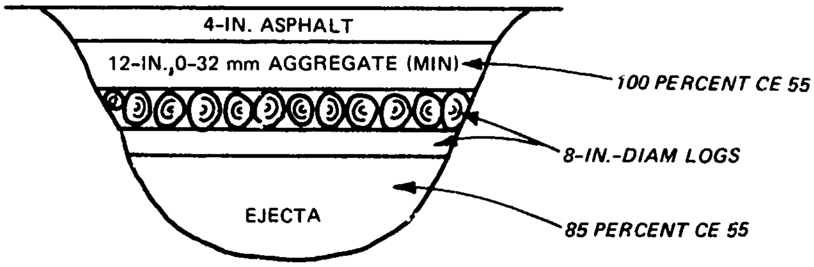


Figure 24

Aggregate Cap

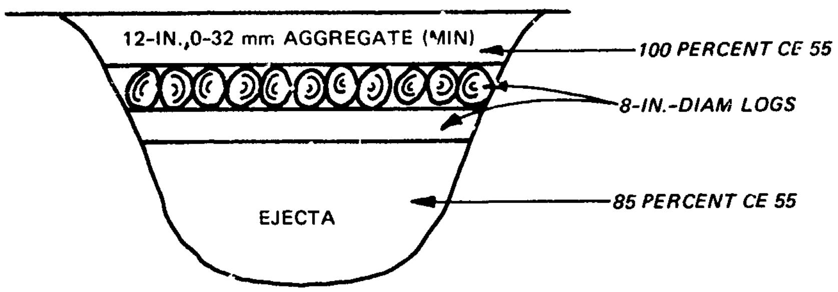


Figure 25

Grout and Stone Cap

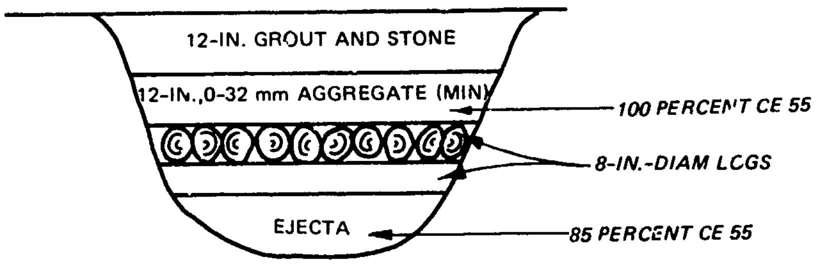


Figure 26

Silikal[R] for Small Craters

Purpose

146. The purpose of this field test of project FEREPS was to evaluate the repair of small craters (5-m diameter) utilizing Silikal[R]* as the capping material. In the past, this battalion has utilized Silikal[R] for small repair with very satisfactory results. Because of this product's excellent characteristics (i.e., high strength, rapid curing (1 hr), at which time load can be applied, and ease of handling), this unit wanted to repair a larger size crater to see if any problems would result and to get a feel for what method should be employed to obtain the fastest production. For the test, two small craters (5-m diameter) were repaired. One crater was repaired utilizing personnel to mix, transport, place, and finish the Silikal[R] cap. The other crater was repaired utilizing equipment to mix (16S Concrete Mixers), equipment to transport and place (5-yd loader), and personnel to finish the Silikal[R] cap. A comparison of the two repair technique methodologies was made to learn which method was better suited for troops and which was faster.

Methodology

147. The methodology employed was developed by members of this unit and representatives of the Karl Ullrich Company K of Zellhausen, which manufactures Silikal[R] in West Germany. The first step involves preparing the crater for select aggregate. Any unsuitable ejecta is immediately removed from the crater and around the crater edges (using the backhoe and loaders), and then any suitable ejecta (less than 12 in. in any dimension) is pushed in from around the crater edges. The ejecta is then leveled and compacted (by piston tampers) to achieve 85 percent CE 55. Then depending on the depth of the crater, sufficient select aggregate (0-32 mm rock) is added in 12-in. lifts and compacted to

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* The use of the Silikal[R] product in this field test does not suggest that the United States Government indorses it. This test was merely conducted to evaluate the repair technique using this product. The results are strictly for research analysis.

95 percent CE 55 until a level 30 cm from the existing runway surface is reached.

148. The next step is to clean the edges of the crater (use compressed air from a 250-cfm air compressor). If the edges are moist or wet, they should be dried to ensure that when added the Silikal^R is able to obtain a good strong bond with the old existing concrete edges. After the edges are cleaned and dried, uniformly graded aggregate (30-60 mm in size) is added until flush with the runway surface. This rock is not compacted because there must be air voids available for the Silikal^R to penetrate through to obtain the necessary strength required. A screed is also passed across the crater surface to identify any rocks that might be pointing up higher than the runway surface. These are removed.

149. The final step is to place the Silikal^R cap over the in-place rock. As mentioned previously, two methods of placement were tried. The first method employed personnel only. The personnel hand-mix the Silikal^R in its mixing bag, transport it to the crater, and pour it on the rock surface. (Note that it should be dropped from a height of 2-3 ft to assist in penetration.) Another group of personnel use a wooden screed to strike off the Silikal^R even with the runway surface (similar to screeding concrete flush with forms). This method is employed across the crater. Following the screed, personnel with trowels finish working the surface to obtain a smooth finish. They also work the edges. The second method employs equipment to mix, transport, and place the Silikal^R and personnel to screed and finish the surface. Concrete mixers (16S) were used to batch larger amounts of the Silikal^R at a time. After mixing for 2 min, the Silikal^R is discharged into the bucket of a 5-yd loader, which then transports the Silikal^R to the crater and pours it over the rocks. (Note that the Silikal^R should be dropped again from a height of 2-3 ft over the in-place rock.) Personnel then screed and finish as before. Figure 27 depicts a cross section of a completed crater repair. As in any crater repair, the runway must be cleared of all remaining debris to prevent FOD.

Test site

150. The battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

151. The craters were constructed using a D7F crawler tractor. Both craters were approximately 5 m in diameter and 1.5 m deep. Ejecta was mounded around the edges of the crater simulating a bomb explosion.

Silikal^R repair

152. Crater preparation. The two craters were prepared, as explained in the methodology section, ahead of schedule. (The change in procedure was necessitated because when LTG Crizer, DCINC USAREUR, visited the REREPS training site on 8 April 1980, he was on a tight schedule. For him to see the Silikal^R being placed, as well as the completed repair before he left, required the preparation of the craters the day before. The outcome or validity of the exercise was not altered in any way because nothing special was done during the preparation, and this activity was timed so that a cumulative total elapsed time could be calculated for the exercise. It took 2 hr to prepare one crater to the point where the only thing left to do was place and finish the Silikal^R cap.) In conjunction with the Ullrich Company personnel, the quantity of bags of powder and barrels of liquid hardener was calculated and placed in stock before the exercise started. For the 5-m crater, 200 bags of powder each and 400 litres of liquid hardener (400 kg in 200-litres barrels) were required. Before the timed start of the exercise on 8 April 1980, the paper bags containing powder were opened, and the powder was placed in the plastic mixing bags. (Note that this would not have added to or subtracted from any time toward the overall exercise time because this very task could have been completed by two employees (EM) in 30 min as the crater preparation was taking place.)

153. The repair on 8 April 1980 commenced at 11 a.m. and followed the sequence of events in Figure 28. Each man of the mixing crew picked up a bag of powder at Point 1 and walked over to the back of the 2-1/2-ton truck (Point 2) where two litres of liquid hardener was added. From

there, the EM walked over to the side of the crater mixing the Silikal^R in the mixing bag on the way (Point 3). Mixing was supposed to be conducted for 1 min, but in the early stages, some EM did not take the full time to thoroughly mix the Silikal^R, resulting in a few dry mixes. This error was corrected as the exercise progressed. After mixing, the EM dumped his bag of Silikal^R in front of the wooden screed board (2 in. by 6 in. by 20 ft with two handles bolted on the ends) (Point 4). From there, the EM walked to Point 5 where he deposited the empty mixing bag on the way back to Point 1. This cycle continued until the repair was complete. When sufficient Silikal^R was built up in front of the screed, the personnel started to work the screed across the crater. Personnel with shovels (two EM) stood in front of the screed to keep the Silikal^R spread evenly in front of the screed. They also placed Silikal^R where needed behind the screed on any missed or low spots. This process also continued across the crater. Once the screed was partially across the crater, the finishing crew started to work the edges, while another EM worked a wooden bullfloat across the large expanse of the crater. This operation continued until the crater was completed at 1140. Total elapsed time then for the repair was:

Crater Preparation	2 hr
Cap Repair	40 min
Curing (before load was applied)	1 hr 20 min
Total	4 hr

154. <u>Crater 2 - machine-mixing method</u>. The organization for repair was as outlined below.

NCOIC	- 1
16S Mixer Crews	- 6
5-yd Loader Operator	- 1
Screed Crew	- 4 EM (on screed board)
	- 2 EM (shovel men in front of screed)
Trowel Crew	- 2 EM
Total	16 EM

Figure 29 depicts the layout for the machine-mixing method at crater 2. As with the hand-mixing method, the batch size (powder and hardener) for the 16S mixer was precalculated, and materials were delivered in a configuration to aid in correct mixing. The two 16S mixers made two

batches each. It was calculated that 18 bags of powder (each 50 kg) and 4 cans of liquid hardener (each 30 litres) were needed per batch.

155. The first step in the mixing sequence was loading the liquid into the machine, then followed by the powder. The liquid was poured in by hand from the drums. The powder was placed on the skip by hand from the bags and then lifted into the mixer by the cable-operated skip. The mixer was to be operated for 2 to 3 min, and then the Silikal^R was to be discharged from the machine. Several problems were encountered in mixing. First, the cable-operated skip did not always work. Thus more time was added to the operation, since the 5-yd loader had to be used to lift it. Another problem was that the calculated amount of mix was too much for the machine to handle. As the mix was being turned in the drum, some of the mix spilled out, mostly liquid, leaving the mix sometimes too dry. Each machine made two batches. The 5-yd loader bucket was used to transport the Silikal^R mix to the crater (Figure 29). The first batch was extremely wet, causing the Silikal^R to penetrate further through the rock than planned. This condition of the first batch also delayed the screeding process because there was not enough mix to screed. The second and fourth batches were good, while the third batch was dry. Screeding and troweling was finally completed at 1200. Total elapsed time then for the repair was:

Crater Preparation	2 hr
Cap Repair	65 min
Curing (before load was applied)	1 hr 5 min
Total	4 hr 10 min

(Note that after the mixing was completed, the 16S mixers and the bucket of the 5-yd loader had to be cleaned. Acetone (30 kg) was placed in the two mixers (15 kg each) to clean the drums and prevent the Silikal^R from hardening. After mixing for a few minutes, the mixture was dumped into the bucket of the 5-yd loader. This mixture also cleaned out the bucket.)

156. Comparisons of the two methods. The most obvious difference between the two methods was the difference in time that it took to complete each crater. The hand-mixing method took only 40 min, while the

machine-mixing method took 1 hr. One of the major goals was to compare the time it took to repair by machine with the time by hand. Probably the biggest factors that contributed to this difference were the following:

a. Personnel were familiar with mixing by hand as they have done this countless times before on spalls.

b. There was no chance of personnel "breaking down" and thereby slowing down the operation. The machines, on the other hand, did break down (the cable-operated skip to load the powder broke and created a delay). One of the disadvantages of the machine method is the reliance placed on the machine. However, with Silikal[R] the hand method can be used if the machines break.

c. This was the first time that our troops attempted to mix Silikal[R] in large quantities in the 16S mixer. Several problems already discussed resulted, such as too large a batch and mix spilling out of the mixer, thereby creating a dry mix. Had a trial batch been made, undoubtedly these problems would have surfaced. By the fourth batch, the batch size had been reduced, less spilling (especially Silikal[R]) from the machine was encountered, and the mixture was very good.

Trafficking of test craters

157. Load cart. A load cart (Photos 15 and 16) was used to simulate the wheel load (front landing gear) of an F-4 aircraft. The total weight over the F-4 wheel was 25,500 lb with a tire pressure equalling 286 psi.

158. Application of traffic. The load cart was positioned in the center of each crater and passed across by backing up the vehicle. All passes were in the same lane. Two ground guides (one in front and one in the rear of the truck) guided the load cart back and forth across the crater. Traffic was applied 1 hr and 20 min after cap completion for the hand-mixed crater and 1 hr after for the machine-mixed crater. The difference in curing times was the result of trafficking the craters at about the same time to accommodate LTG Crizer's seeing the results. The completion of the hand-mixed crater 20 min before the machine-mixed crater accounts for the longer curing time. However, the Ullrich Company personnel said that 1 hr was sufficient time to obtain the necessary strength.

159. Behavior of test craters. After only 10 passes over the crater mixed by hand, stress cracks were observed in the Silikal^R repair. The cracks ran longitudinally along the lane of traffic. On the machine-mixed crater, the load cart broke through the cap near the far edge of the crater on the first pass. Both caps exhibited elastic deformation as the wheel passed over.

Analysis of results and conclusions

160. Analysis of results. Of the two crater repairs, the hand-mixed crater not only was faster but showed the best performance. It is unknown how many more passes the crater cap could have withstood, but it was evident that the cracks were getting larger as more passes were applied. A cutout section later revealed that the Silikal^R had only penetrated to a depth of approximately 10 cm instead of the planned 15 cm. The major reasons probably are: (a) the aggregate was covered by a thin coating of dust, which came from sweeping the pad before the cap was placed; and (b) the aggregate was a graded 30-56 mm size. It would have been better to obtain a 45-56 mm size aggregate. The machine-mixed crater, as previously mentioned, failed on the first pass in one area near the edge (the failure was 1 m long by 0.6 m wide with upheaved sections). A cross section of the cap revealed that the Silikal^R had only penetrated through the aggregate 6 cm in this particular spot. It was also very evident that the mix in this area had been extremely dry, reducing the strength even more. As noted in the hand-mixed crater, the surface of the aggregate was coated with dust before placing the cap. Both craters also experienced the edges cracking away because the personnel troweled the Silikal^R over the existing concrete edge. Thus, when the load cart was applied over the edge, the edges cracked, creating loose sections of Silikal^R (thin, wafer-like sections approximately 2 by 5 cm).

161. Conclusions. The conclusions arrived at following the exercise are:

a. The hand-mixed/placed method was faster than the machine-mixed/placed method. However, this does not totally rule out the use of machines to batch large quantities, if several points are kept in mind.

First, to be proficient with machines, practice is a must. Secondly, the 16S mixer may not be well-suited to batching Silikal^{R}, and so a more reliable machine, such as the concrete mobile, should be used.

b. The hand-mixing/placing method has the biggest advantage of no possible equipment breakdown. It also is simple to do.

c. A slightly larger aggregate size of 45-56 mm may work better to allow the greater penetration (15 cm) of the Silikal^{R} to give the required strength. It is also preferable to have the aggregate clean, so a better bond between it and the Silikal^{R} can be achieved.

d. For quick repair on any size crater, repair with Silikal^{R} as the capping material offers a viable alternative.

Cross Section of Completed Crater Repair with Silikal[R]

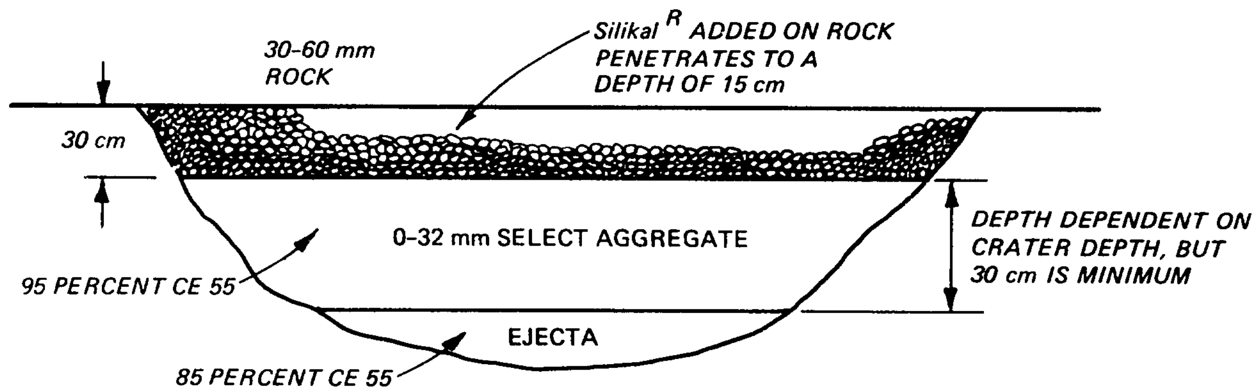
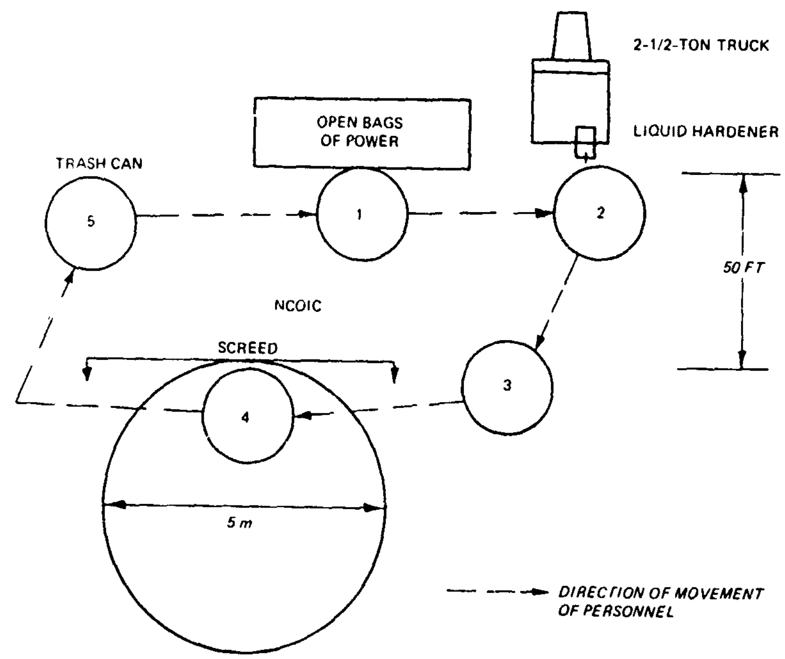


Figure 27

Crater Site 1 Layout for the Hand-mixing Method



CRATER SITE 1 LAYOUT FOR THE HAND-MIXING METHOD

Figure 28

Crater Site 2 Layout for the Machine-mixing Method

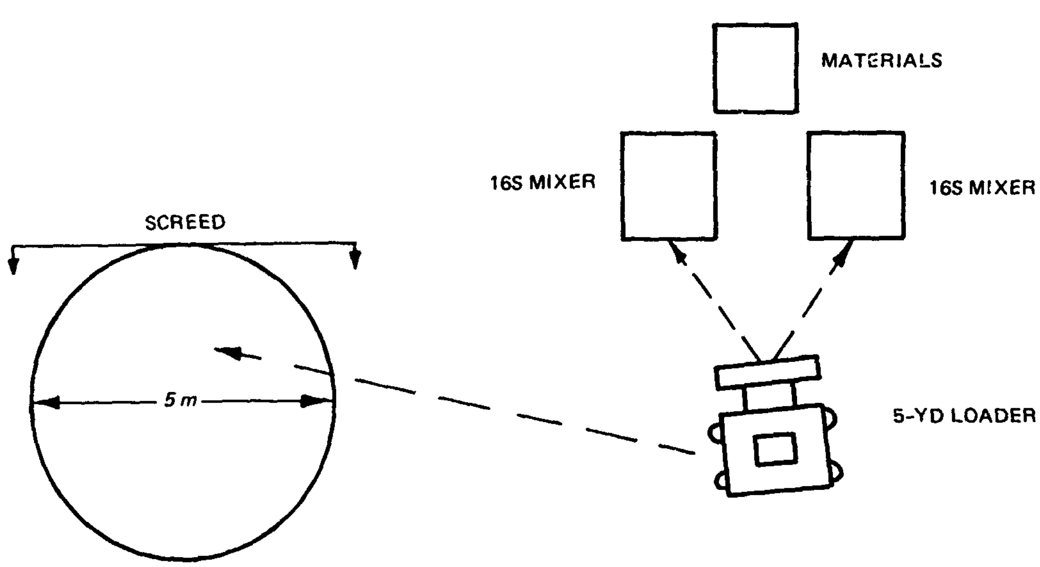


Figure 29

Regulated-Set Concrete for Small Craters

Purpose

162. The purpose of this field test of project REREPS was to introduce the technique of using regulated-set concrete to the personnel in the unit and to evaluate the adequacy of such a repair on a small crater.

Background

163. This unit has conducted numerous crater repair exercises with regulated-set concrete over the past several years on large craters. There are two volumes of information in the 293rd Engineer Combat Battalion's library covering many aspects of the training and testing conducted. The mix design that was used in the crater repair exercise conducted on 12 April 1980 was obtained from these volumes.

164. One of the principal reasons that regulated-set concrete was so extensively tested by this battalion was the requirement to rapidly repair a damaged bomb crater within 4 hr and have that repair be able to withstand a load immediately. The use of regulated-set concrete permitted the unit to meet the requirement because of its characteristics of setting up very rapidly and achieving the necessary strength (1000 psi) within only 4 hr. The last regulated-set exercise was conducted in March 1979.

165. Several problems have always occurred with the use of regulated-set concrete, however. One major problem for the contractor is the storage requirements of Schnell cement, that is, it must be kept completely dry. Also, the aggregates that are used in the mix must be kiln-dried before using to ensure there is no retained water to start the process of hydration before the mixture actually is needed. Another problem for the unit is the requirement to add water onsite as well as a retarder or accelerator, depending on the ambient temperature. (Note that retarder is added when the ambient temperature is above 32°F.) If the ambient temperature is below 32°F, the water being used in the mix must be heated so that it does not freeze. The addition of the correct amounts of water and retarder/accelerator has created several

problems in the past. The distributor vehicle holds only a 1000 gal of water, and the gage is not very accurate. Consequently, several mixes may be either too wet or too dry before the correct amount can be added. The same also applies to the use of retarder/accelerator, which must be added onsite into the mix trucks. Since the amount added is tied to the ambient temperature as well as to the weight of the Schnell cement (the quantity added is a percentage of the weight of the Schnell cement in the mix), trial and error methods must be relied on. Barring these problems, however, to maintain the unit's experience with this particular method of repair, a small crater exercise was therefore scheduled and conducted. (Note that there is one other problem or drawback. All Schnell cement in Germany is made by the Heidelberger Schnell Cement Plant, and it only has a storage shelf life of 6 months to 2 years.)

Methodology

166. The methodology employed in the small crater repaired on 12 April 1980 was essentially a three-phase operation; crater preparation, cap repair, and runway cleanup. Crater preparation consists of clearing away all unusable ejecta and debris from around and within the crater until a depth 36 in. below the existing runway surface is obtained. This layer is then compacted to 85 percent CE 55 by hand tampers. Select aggregate (0-32 mm gradation) in two lifts of 12 in. each is then back-dumped or pushed into the crater by a front-loader and compacted by vibration until 100 percent CE 55 is obtained. The crater edges are then cleaned by personnel with brooms and/or blown clean using compressed air from a 250-cfm air compressor. This procedure ensures that all loose dirt is removed so that a good bond can be obtained between the new regulated-set concrete cap and the old existing concrete edge. The next step is to mix and add the regulated-set concrete into the crater, then screed and finish the surface. The regulated-set concrete can only be worked between 10 to 40 min before setting, depending on the amount of retarder added. After the surface is finished (using wooden floats), the concrete is allowed to cure. The cure time before a load is applied varies from 1 to 3 hr, depending on the amount of retarder added.

Test site - construction of crater

167. The battalion's test site is located in Baumholder, Germany, just east of the airport (Photo 1). It is a concrete slab 30 m wide by 120 m long. Ninety metres of the length is 0.33 m thick, while the remaining 30 m is 0.15 m thick.

168. The crater was constructed using a D7F crawler tractor and was approximately 6 m in diameter and 1 m deep. Ejecta was mounded around the edges of the crater simulating a bomb explosion.

Crater repair

169. Crater preparation. Crater preparation proceeded as follows. At 0820, a loader began to clear debris from around the crater edge. Personnel with shovels leveled the ejecta inside the crater and used hand tampers to compact it to 85 percent CE 55. This step was completed at 0833. Select aggregate (0-32 mm gradation) was then back-dumped from 20-ton dump trucks into the crater until a 12-in. lift was created. (Figures 30 through 33 present data describing the select aggregate material.) Again personnel leveled the aggregate and used both hand tampers and a plate compactor to compact the area. At 0912, the second 12-in. lift of aggregate was added. This lift was completed at 0955. At this time, personnel using brooms swept the edges clean of any loose dirt. A 5-ton dump truck with air hose was also used to blow the edges clean. At 1000, crater preparation was completed.

170. Regulated-set concrete cap. As mentioned previously, the mix design for the regulated-set concrete was obtained from two volumes of information in the library of the 293rd Engineer Combat Battalion. This particular mix design was based upon extensive research between this battalion, WES, Heidelberger Schnell Cement Company, and Nahe-Beton (the contracting firm who delivered the concrete). Furthermore, this particular mix design has been shown to give the best results. The mix is delivered to the site dry (no water), consisting of the following materials that are proportioned on the basis of 1 cu m:

Portland cement 450F, modified, type Heidelberger Schnell cement	430 kg
Sand 0-2 mm DIN 4226, sh 1	560 kg
Aggregate 2-8 mm DIN 4226, sh 1	380 kg

Aggregate 8-16 mm DIN 4226, sh 1		580 kg
Aggregate 16-32 mm DIN 4226, sh 1		130 kg

The dry mix is delivered in transit mix trucks to the runway repair training site where water is added. A water/cement (w/c) ratio of 0.52 was used that amounted to slightly more than 400 gal per 5-cu-m truckload. To increase the workability of the mix for a longer period, addiment Schnellzement Verzoegerer (retarder) liquid was added on the basis of 0.3 percent of the cement weight per cubic meter or 3 gal per 5-cu-m truckload. (Note that the cost of 1 cu m of regulated-set concrete via transit truck was 260 deutsche marks (DM). On this particular exercise, 15 cu m was ordered for a total cost of 3900 DM or $2100.)

171. The first truck of dry regulated-set concrete arrived at the training site at 1023. Then following the plan for the exercise (Figure 34), the concrete transit truck was backed up to a 5-ton dump with the 1000-gal water distributor on the opposite side. The 5-ton dump bed served as a platform for a man to stand on so that he could reach the opening on the top rim of the concrete transit truck and insert the water hose. At 1035, the water was turned on and flowed into the concrete truck. However, personnel failed to check out the valves of the water distributor, and water came out not only through the hose but also through the spray bar. Consequently, the water being added to the truck could not be accurately measured, and the first truck had to be dumped offsite. The valves were worked on for the next few minutes and finally closed. The time was now 1058. The truck had used quite a lot of water in this process, so it had to go back to the refill point. It left and arrived back onsite at 1115. At 1049, the second truck arrived and, of course, had to wait until the water distributor returned. At 1118, the second concrete truck had water and retarder added to it. The amount of water added was regulated by watching the gage at the rear of the water distributor and by also observing the concrete as it was being mixed in the concrete truck. The concrete was mixed for 5 min (the drum of the concrete truck was revolved at its fastest speed to aid in thorough mixing). Three gallons of retarder were added about 1 min into the mixing from the back topside of the concrete

truck. After mixing, the concrete truck moved over to the crater and discharged its load. The consistency was somewhat wet at first, but as the truck continued to discharge its load, the consistency became drier. At 1127, the third concrete truck arrived; at 1133, water was being added. The same procedures were followed for the second truck; at 1145, the truck placed its load in the crater. The consistency of this mix was excellent. As the second truck was being placed, the screeding operation had already begun. The screed beam consisted of 2- by 8-in. material having two handles bolted to each end. After the concrete had been screeded, the surface was bullfloated using long-handled wooden bullfloats, and the edges were finished using wooden floats and steel trowels. The crater cap was completed at 1210 and was then allowed to cure before load was applied.

172. Runway cleanup. As with any other runway repair, the surface of the runway must be swept clean of any foreign objects (stones, dirt, etc.), which could be ingested by an airplane engine and cause serious damage. Following the completion of placing the crater cap, a rotary sweeper towed by a jeep was used to clean the runway surface (Photo 47).

Trafficking of test crater

173. Load cart. A load cart (Photos 15 and 16) was used to simulate the wheel load (front landing gear) of an F-4 aircraft. The total weight over the F-4 wheel was 25,500 lb with a tire pressure equalling 286 psi.

174. Application of traffic. The load cart was positioned in the center of the crater and passed across by backing up the vehicle. All passes were made in the same lane. Two ground guides (one in front and one in the rear of the truck) guided the load cart back and forth across the crater. Traffic was applied to the crater 2 hr after it was completed (at 1410).

175. Behavior of test crater. The load cart cracked the edge in one spot as it moved across the crater. All other places did not deflect at all. It was evident that this particular small area had not cured sufficiently to achieve a great enough compressive strength to withstand the load.

Analysis of results and conclusions

176. Analysis of results. Since the one area failed, the repair was not totally successful. Several reasons may have contributed to this failure. Probably the most important factors are the amount of water and retarder added. Since the exact amount of water added to the concrete truck containing the dry mix could not be adequately gauged, the strength of the resulting concrete produced was therefore affected. A more accurate way to measure the amount of water added is needed. Secondly, the addition of too much retarder prevented the curing process from proceeding as rapidly as it should. Thus, it would have been better to add only 0.1 to 0.2 percent by weight of cement (1 to 2 gal) of retarder per 5 cu m of regulated-set concrete. However, trying to convince the German contractor to make this change is sometimes difficult, for he is naturally concerned with the concrete setting up in his truck and wants as much time on his side as possible. This unit has been fortunate to have had good working relationships with Herr Effinberger of the firm Nahe-Beton throughout the exercise.

177. Conclusions. After a review of the results, it was concluded that:

- a. Regulating the exact amount of water added to the concrete mix truck is a must. The equipment on hand is not sufficient to provide an adequate measuring capability.
- b. The amount of retarder added is a key factor in determining when the concrete cap can be loaded. If too much retarder is added, the required strength will not be reached within the required time because the chemical reaction of hydration will have been slowed down. If not enough is added, there is the risk of the regulated-set concrete setting up too fast. Since the retarder is dependent on the ambient air temperature, it must be added onsite.
- c. There is only one plant in Germany that produces this Schnell cement. It must be strictly controlled, as far as moisture is concerned, to keep it dry. The aggregates too must be kiln-dried to remove any water. Would these type facilities be available in a wartime situation? It is highly unlikely. The WES reached similar conclusions in the draft report, "Evaluation of Regulated-Set Cement Concrete Repair Procedure," dated May 1979.

SIEVE ANALYSIS

Date 24 Mar 80

Project REREPS 80-2

Boring No. ______ Sample No. Sharp angular shale

Total wt in grams of sample, W_s = 2059 | Wt in grams of material > No. 4 sieve =

Sieve Openings		U. S. Standard Sieve Size or Number	Weight Retained in grams	Percent Retained		Percent Finer by Weight
Inches	Millimeters			Partial	Total	
3.00		3-in.	0		0	2059
2.00		2-in.	0		0	2059
1.50		1-1/2-in.	0		0	2059
1.00	25.4	1-in.	295		14.3	1764
0.750	19.1	3/4-in.				
0.500	12.7	1/2-in.	488		38.0	1276
0.375	9.52	3/8-in.	232		49.3	1044
0.250	6.35	No. 3				
0.187	4.76	No. 4	426		70.0	618
		Pan				
0.132	3.36	No. 6				
0.094	2.38	No. 8				
0.079	2.00	No. 10				
0.047	1.19	No. 16	425		91.6	193
0.033	0.84	No. 20				
0.023	0.59	No. 30				
0.0165	0.42	No. 40	115		96.2	78
0.0117	0.297	No. 50				
0.0083	0.210	No. 70	42		98.3	36
0.0059	0.149	No. 100	7		98.6	29
0.0041	0.105	No. 140				
0.0029	0.074	No. 200	10		99.1	19
		Pan				
Total weight in grams						

$$\text{Partial percent retained} = \frac{\text{wt in grams retained on a sieve}}{\text{wt in grams of sample used for a given series of sieves}} \times 100$$

$$\text{Total percent retained} = \frac{\text{wt in grams retained on a sieve}}{\text{total wt in grams of oven-dry sample}} \times 100$$

For an individual sieve, the percent finer by weight = percent finer than next larger sieve - percent retained on individual sieve

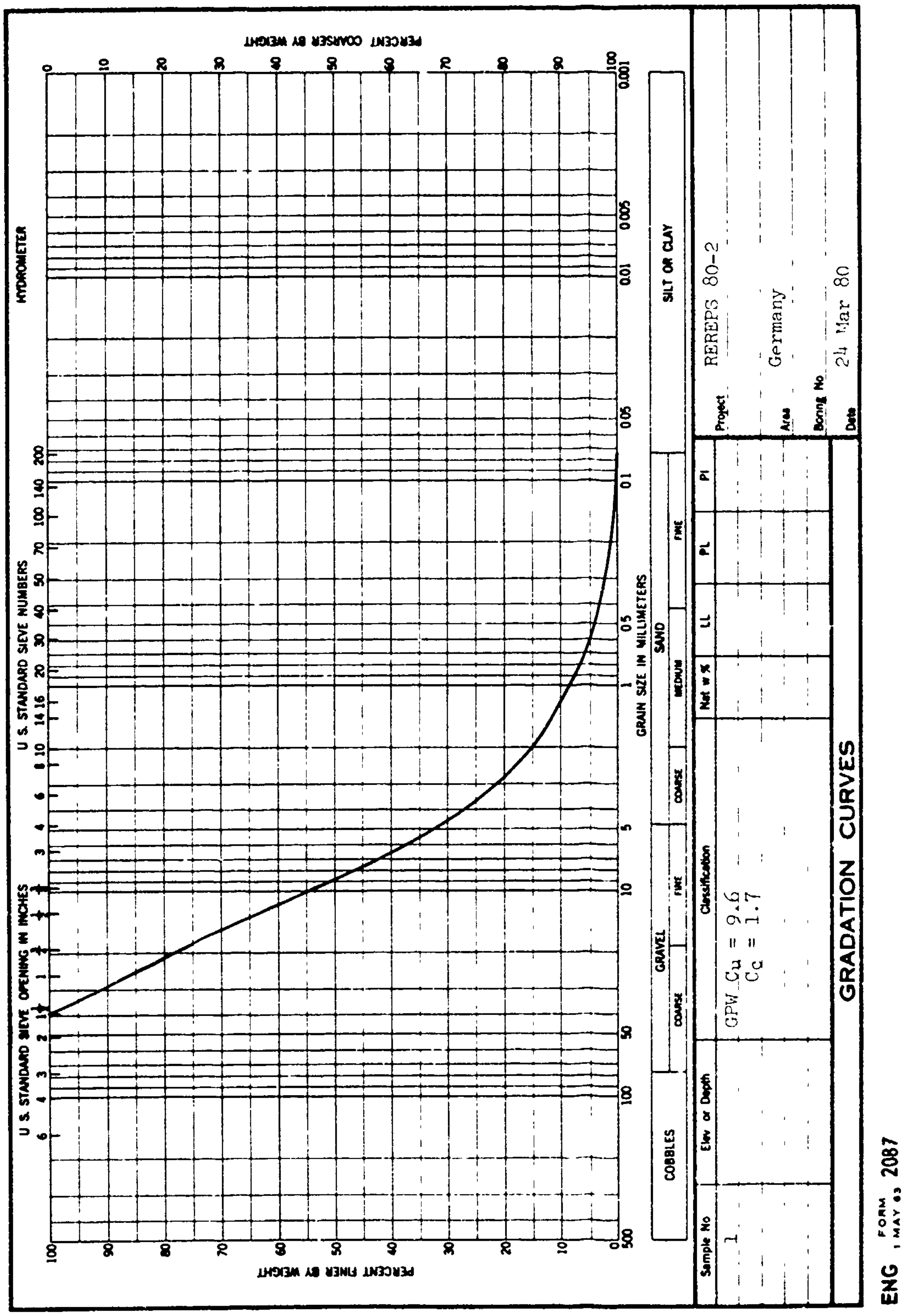
Remarks

Technician SO4 DeWire Computed by ______ Checked by CPT Reed

ENG FORM 1 JUN 66 3841

PLATE V-1

Figure 30


GRADATION CURVES
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U.S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
SAND
SILT OR CLAY
Sample No
Elev or Depth
Classification
Nat w %
LL
PL
PI
1
GPW Cu = 9.6
Cc = 1.7
Project REREPS 80-2
Area Germany
Boring No
Date 24 Mar 80
ENG FORM 1 MAY 63 2087

Figure 31

SOIL COMPACTION TEST DATA

DATE: 25 Mar 80

PROJECT: REREPS Stockpile	EXCAVATION NUMBER: NA	SAMPLE NUMBER: NA	NUMBER OF LAYERS: 5

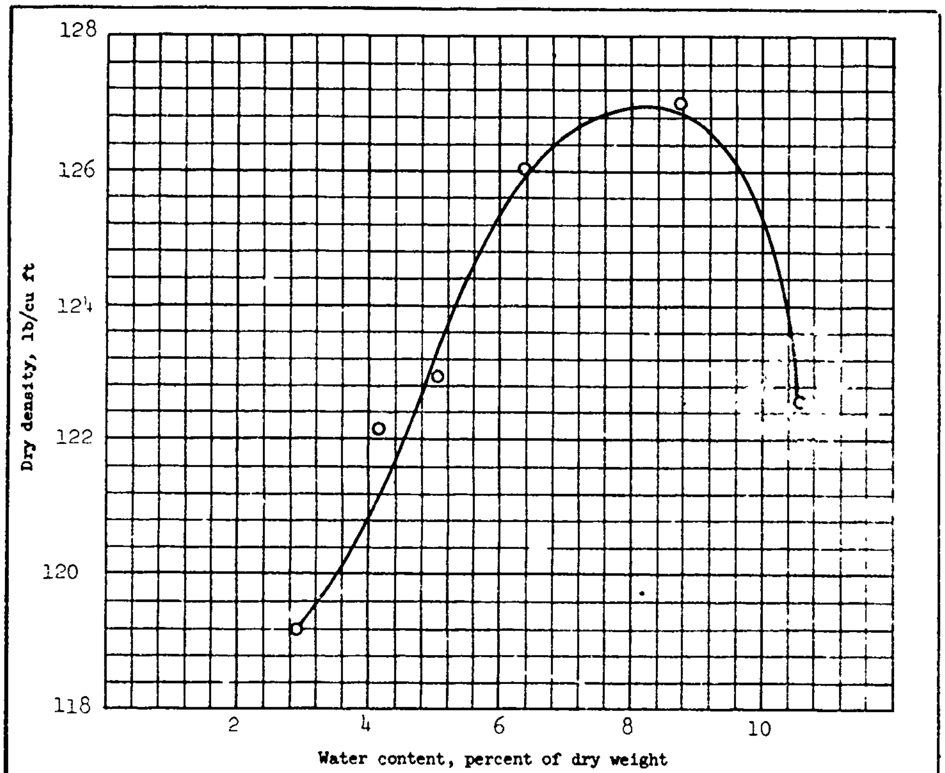
CONVERSION FACTORS 1728 cu. in. per cu. ft. 453.6 gm. per lb.	NUMBER OF BLOWS PER LAYER: 55	WEIGHT OF TAMPER: 10#	HEIGHT OF DROP: 18"	MAXIMUM PARTICLE SIZE: 1/2"
	SPECIFIC GRAVITY:	DIAMETER OF MOLD (in): 6"	HEIGHT OF SOIL SAMPLE (in): 4-1/2"	VOLUME OF SOIL SAMPLE (cu ft): 0.025 ft^3

	UNITS												
RUN NUMBER		1		2		3		4		5		6	
WEIGHT OF WET SOIL + MOLD		8361		8520		8585		8743		8888		8794	
WEIGHT OF MOLD		4181		4181		4181		4181		4181		4181	
WEIGHT OF WET SOIL		4180		4339		4404		4562		4707		4613	
WET UNIT WEIGHT, $\gamma = \left(\frac{\text{Weight of wet soil (lb)}}{\text{Vol of soil sample (cu ft)}}\right)$	LB. PER CU. FT	122.8		127.5		129.5		134.1		138.4		135.6	
TARE NUMBER		B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9	B-10	B-11	B-12
A. WEIGHT OF WET SOIL + TARE		231	235	244	246	201	255	266	287	315	292	258	297
B. WEIGHT OF DRY SOIL + TARE		226	230	236	238	193	245	254	272	292	274	238	273
C. WEIGHT OF WATER, W_w (A - B)		5	5	8	8	8	10	12	15	23	18	20	24
D. WEIGHT OF TARE		52.5	51.0	52.5	51.5	53.0	52.0	52.0	52.0	51.0	52.0	52.0	52.0
E. WEIGHT OF DRY SOIL, W_s (B - D)		173.5	179	183.5	186.5	140	193	202	220	241	222	186	131
WATER CONTENT, $w = \left(\frac{W_w}{W_s} \times 100\right)$	PERCENT	2.9	2.8	4.4	4.3	5.7	5.2	5.9	6.8	9.5	8.1	10.8	10.4
AVERAGE WATER CONTENT	PERCENT	2.9		4.4		5.5		6.4		8.8		10.6	
DRY UNIT WEIGHT, $\gamma_d = \left(\frac{\gamma}{1 + w/100}\right)$	LB. PER CU. FT.	119.3		122.1		122.7		126.0		127.2		122.6	

TECHNICIAN (Signature): SP4 DeWire	COMPUTED BY (Signature): SP4 DeWire	CHECKED BY (Signature): CPT Reed

DD FORM 1 AUG 57 1210

Figure 32



_______________ compaction test

_________ blows per each of ____________ layers, with ____________ lb rammer and

________ inch drop. ____________ inch diameter mold

Sample No.	Elev or Depth	Classification	G	LL	PL	% > No. 4	% > 3/4 in.

Sample No.				
Natural water content, percent				
Optimum water content, percent	8.8			
Max dry density, lb/cu ft	127.6			

Remarks	Project REREPS Stockpile (0-32 mm)	
	Area	
	Boring No.	Date 26 Mar 80
	COMPACTION TEST REPORT	

ENG FORM 1 JUN 65 2091 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT)

Figure 33

Setup for the Regulated-Set Exercise

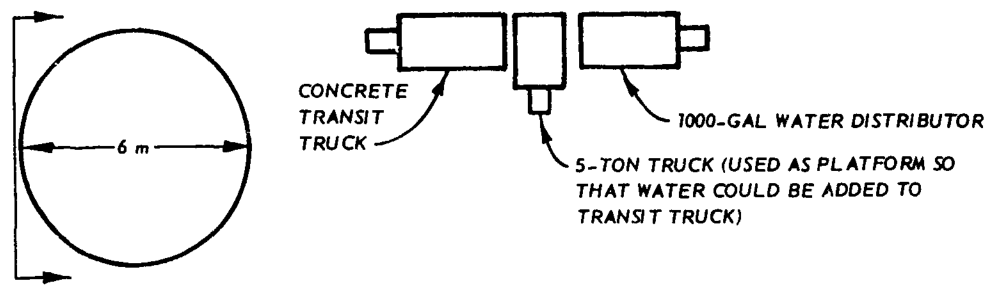


Figure 34

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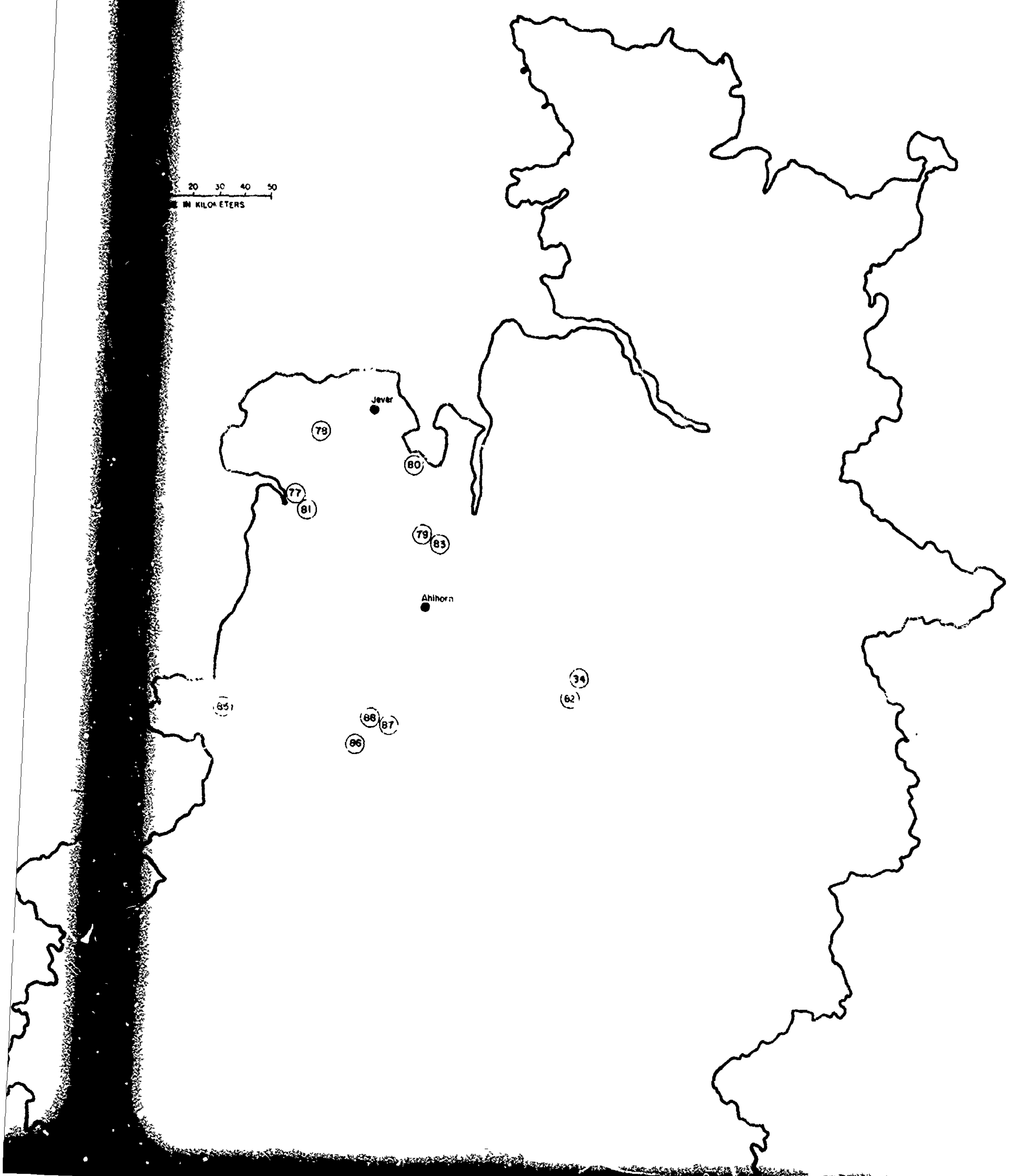

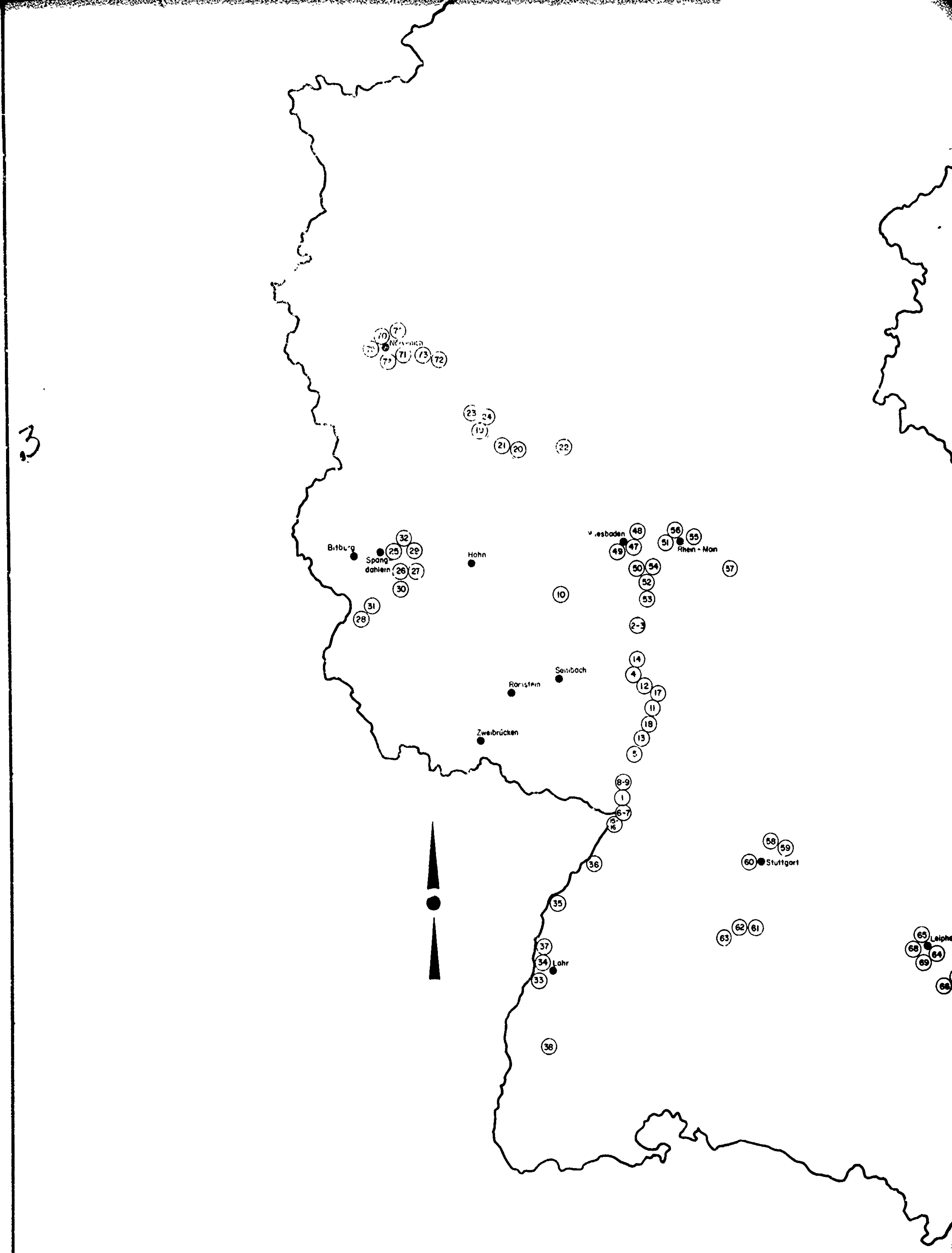
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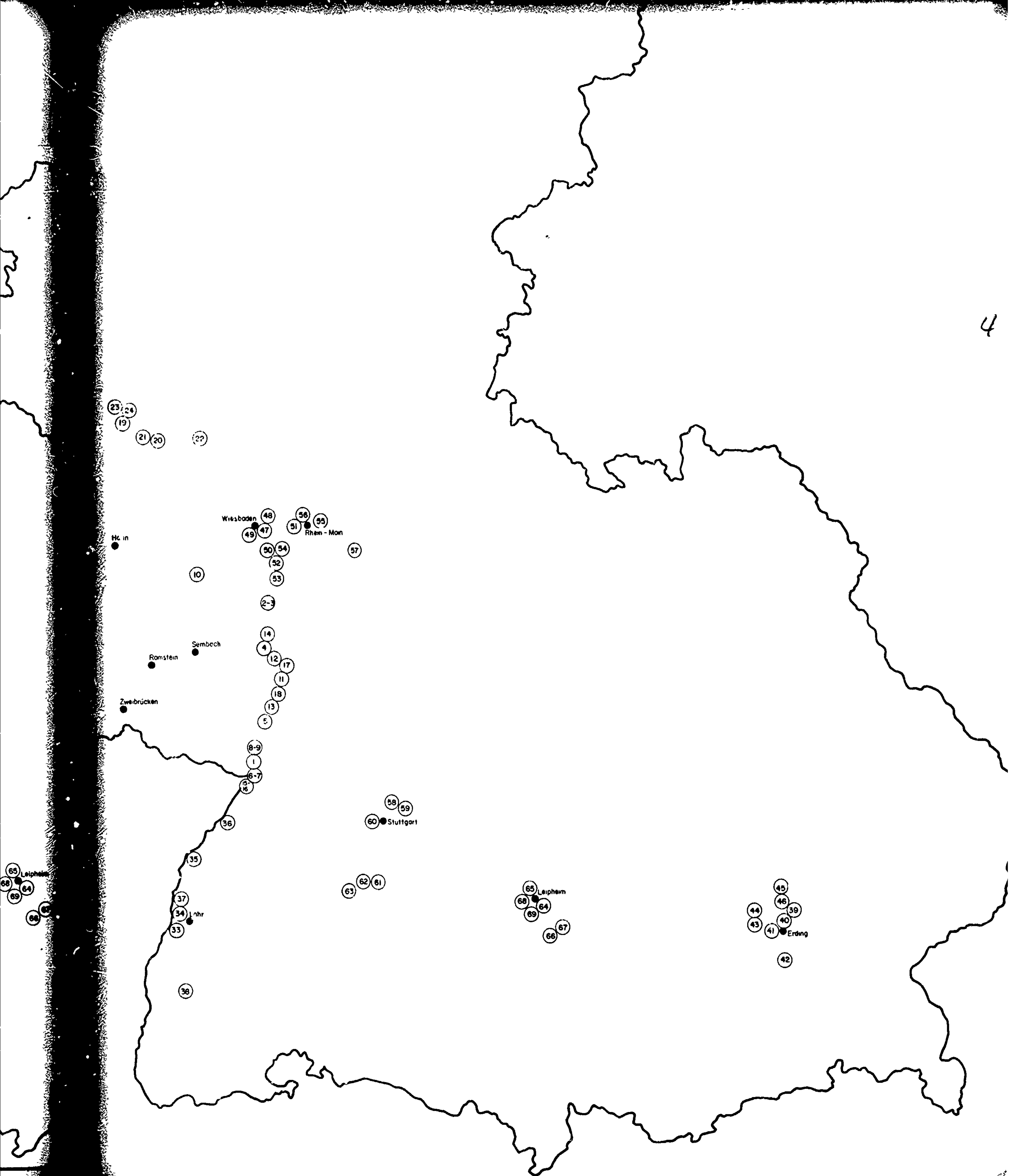
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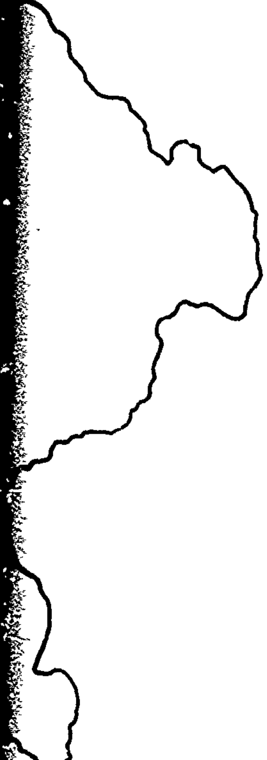

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